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METALLURGIA

THE BRITISH JOURNAL OF METALS


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METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER.)

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OCTOBER, 1940. VOL. XXII. No. 132.

Growing Use of Minerals

Primitive man had few utensils and no machines worth mentioning, but the things that made history, that helped him most in his struggle for existence and towards a more abundant life, were things of metal. To-day, the material welfare of a nation can be measured by its consumption of minerals, the application of which, as Paul M. Tyler points out, indicate man's progress in physical comfort and well-being. His views on various aspects of the growing use of minerals, particularly metallic minerals, are given in this article; prophecy with regard to what lies ahead for minerals, but the demand for minerals cannot be expected to grow for ever, and the question is raised as to which minerals are likely to be most successful in the future.*

THE total consumption of metals and minerals during all the centuries before 1800 was quite insignificant compared with modern needs—probably less than it is now in a single year,—and the total output of the world's mines, quarries and wells before 1900 failed to equal the quantity produced during the last 30 years. In the hundred years from the close of the Napoleonic wars to the outbreak of the World War in 1914, the white population increased three-fold, but the output of tin increased 26-fold, of copper 63-fold, of the mineral fuels 75-fold, and of pig iron over 100-fold. Lead and zinc showed corresponding increases. Contrary to popular impression, the World War—or, as pessimists are beginning to call it, World War I—did not increase the supplies of most minerals. Not until after 1922 was the upward trend confirmed. By 1929 the index of total output of leading minerals jumped to 136, compared with 78 in 1914, and after dropping to 88 in 1932 it rapidly recovered and reached a record in 1937.

Canadian Pacific Photo

Smelting Works at Tadamac, B.C.

More striking almost than the increase in volume is the increase in variety of industrial raw materials. Until Revolutionary days, foods, fibres and wood were the chief materials of industry, and not more than half a dozen metals were employed to any appreciable extent. As recently as the beginning of the present century, the list of useful metals comprised iron, copper, lead and zinc, supplemented by very small quantities of tin, antimony, gold, silver, platinum, and a few minor metals. Mercury and bismuth were used medicinally and to a meagre extent in the arts, but nickel and cobalt, in common with manganese and silicon, were employed but little outside of the steel industry. The chemical industries and other large industrial consumers of mineral raw materials were in their infancy, and even architects and builders were satisfied with relatively few kinds of structural materials. Coal or peat, clay for the potter and bricklayer, sand for glass-makers, salt, whetstones and millstones, and perhaps a little mica were virtually the only non-metallic minerals needed, apart from building stone.

The main achievement of the 19th century was the rise of heavy industries and factory production. As steam relieved the more arduous drudgery, the Industrial Revolution sought first to provide more abundantly the primitive wants of the common people. There was little demand for materials other than those already at hand. Men and women in the lower income groups had to be furnished with adequate food and clothing before they could be made to buy motor-cars, radios, and more complicated things that had not yet been invented. Diversity in manufacturing industries with its accompanying demand for a larger and larger assortment of raw materials was a later development.

Increasing Demand

No limits can be set upon the volume of total goods and services that can be made and sold, for human wants are insatiable. Beyond certain flexible limits, however, an increased volume of sales can be attained only by increasing the variety of goods offered. A hungry man may want food above all else, but once his hunger is satisfied he begins to want other things more. The law of diminishing returns is a fundamental principle of economics and explains the eagerness of motor-car manufacturers, for example, to build radios, refrigerators, air-conditioning equipment, and other products which add to the convenience of living. To meet the increasing demands, new metals emerged from the laboratories, one by one, and found applications. During the first three decades of the present century, the number of metals in active use more than doubled, and research proceeds to-day at a still quicker pace to expand our knowledge, and, if possible, our utilisation of all the 92

* Bureau of Mines Information Circular 7118, 19 pp.

elements that chemists recognise as comprising the essential materials.

Invisible Uses of Metals

Many modern uses of metals are invisible, and in many important uses the services rendered by minerals are unrecognised except by those who actually make the products or supply the materials. Even those who know that the slender filament of an incandescent lamp is tungsten may never have stopped to think that were it made of a less efficient material, which formerly was employed for the same purpose, four times as much current would be required for lighting. In other words, in this instance, a few pounds of the right metal takes the place of tons of costly apparatus for the generation and transmission of unnecessary electricity, releasing corresponding quantities of fuel or power for other industrial uses. Still more economical are the new fluorescent lamps, which likewise owe their high luminous efficiency to rather minute quantities of metal salts. Relatively few persons realise that the life of a tungsten filament is prolonged by "flashing" the bulb with a pinch of zirconium or other oxygen-hungry metal, and by filling the bulb with an inert gas captured from the atmosphere and concentrated, or that traces of thorium or other rare metal may be used to make the tungsten ductile enough to be drawn into a filament. A tenth of 1% of copper delays corrosion of steel; a similar amount of molybdenum or vanadium makes it stronger and tougher. A few hundredths of 1% of tellurium harden and toughen lead to an amazing degree. Five parts per thousand of tetra-ethyl lead give petrol anti-knock properties, and 15 parts per million of silver are used in the purification of water and alcohol.

Many people are now familiar with the fact that steel is made stainless by combining it with chromium, but the man in the street may not know that stream-lined designs requiring welding could not be achieved if the stainless properties of the alloy were not stabilised and protected, for which purpose minute additions of columbium or other rare metal may be used. The less common metals are a far larger factor in our modern life and industry than is generally appreciated. Because their main functions are to enhance the properties of other materials, many alloying metals seem destined forever to act behind the scenes, and may never aspire to more than insignificant rank in the value of products. Mica is one of the most modest of minerals, and is less well known now than it was in earlier days, but to-day it has a hundred new uses in the electrical industries.

The human body contains a dozen or more mineral elements, and lack of a tiny trace of even one of them can completely alter the state of health. Important elements in human architecture and bodily well-being are sodium, phosphorus, calcium, magnesium, sulphur, iron, manganese, copper, zinc and cobalt, as well as several other non-metal elements. Rickets has been attributed to lack of vitamin D, but deficiency of phosphorus and calcium is equally serious. All three are required for good bones. Lack of a seemingly trivial quantity of copper may cause pernicious anæmia. Small quantities of manganese are essential to motherhood and help in the growth of children. "Bush sickness" in cattle and sheep has been attributed to a shortage of cobalt. Other elements are seemingly needful in small amounts.

Basic Industries Dependent on Minerals

Agriculture and mining are the basic industries. Every material thing that men need comes from the earth—everything we eat, drink, wear or use, and all dwellings, conveyances, tools, necessities, or luxuries. Agriculture depends in part on mining, and many industries have been built and depend upon mineral raw materials, therefore it can be truly said that minerals hold a dominant place in modern life. It is impossible, however, in this relatively short article to do more than suggest the manifold applications of minerals. But it is important to inquire whether we shall keep on needing more and more kinds of minerals in ever-increasing quantities. This is not merely an academic question, and it concerns not only mineral industries, but looms large in national and international politics. Minerals are tremendously important from a strategic point of view, and afford one of the prime motives for wars such as are now raging. The "have-not" nations want to be assured of supplies of mineral raw materials on terms satisfactory to them.

Will Growth be Continuous?

It is customary always to expect continued growth. Little businesses expect to grow big, and big businesses expect to grow bigger. A little more than a quarter of a century ago there was no limit to optimism. Since then war, readjustment, depression and recovery have been experienced, and, prior to the present hostilities, we had become a little more hopeful again, though confidence in unlimited growth had been shaken. The world outlook is too confused to permit a definite statement on which industries are going downhill and which are still in process of vigorous growth. The world coal output has virtually ceased to grow, but declines in the United States and Great Britain are partly offset by increases in Germany and the Soviet Union. Petroleum production keeps on rising steadily. With regard to pig iron, the trend is not so clear, but increases in several producing countries seem to have offset decreases in others, and this is certainly true of the main non-ferrous metals—copper, lead and zinc. The light metals—aluminium and magnesium—are being produced in continually increasing quantities, as are also most of the minor or, rather, rare metals. Even tin production, after threatening to continue in decline, recently has resumed a rising trend.

Many believe firmly in increased consumption of goods, but it does not follow that the demand for minerals will keep on growing for ever. For the moment, let us ignore substitution and consider whether we are not reaching gradually the stage where our appetite for minerals will be more nearly satisfied and we shall want other things more. The world of civilisation has developed many turning points. Primitive peoples progressed from a pastoral to an agricultural economy. There was a time when the building of pyramids consumed most of the surplus energies of the then civilised world. Later came the development of the Jewish religion in Palestine and the spread of commerce by the Phœnician merchants. The flower of Greek civilisation was its sculpture, architecture, and perhaps the beginning of philosophy. The Romans developed road building, public works, and military strategy, and codified the laws that have helped to define the relations between individuals and the State. The Renaissance in Europe was a period of change; it was followed by the Reformation, and preceded by other religious movements of profound significance, of which the Crusades were but one example. A period of colonisation was ushered in by the discovery of America. Three centuries later the widespread demand for individual liberty manifested by the American and French Revolutions almost obscured, at the time, the beginning of the Industrial Revolution. Are we still in the era that began after James Watt first contrived, in 1775, to harness steam? It would seem so, but it is not impossible that a new era is in the making. In any event, as previously stated, the economic changes of the present era have come in a series of waves. In terms of minerals, the need for coal to burn under boilers came first, next the demand for metals to make machines, and later the demand for more diverse materials, for ever more complex products and services. The outposts of science are spread so wide that it is difficult now to determine which frontiers are being pushed ahead fastest. Transportation and communications seem to have progressed more than housing. The swiftest advance of all however, seems to be in the synthesis of chemical compounds. The modern chemist is an architect and builder. He builds molecules almost as a mason builds a wall, and for his atomic building blocks he is beginning to use the materials closest to hand. In a few years he may even be able to trim his atoms to suit his needs.

Refinement Trends

Statisticians, like surveyors, need foresight before laying out a future course, and in economic affairs the visibility is seldom perfect. Moreover, until the technique of statistical forecasting is improved further it is hazardous to prophesy what lies ahead for minerals, which industries are dying out, or which are destined to grow even faster. Most of the new services offered to-day—such as rapid transport, radio, television, air conditioning—demand minerals, but generally not in great bulk. Already we are using more fine steel and less common pig iron, more refined products in every field. Almost every modern product is vastly superior to that of a generation ago; it is designed with great care, made from carefully controlled material, and the method of manufacture is more refined and precise. Even aluminium leg bands for carrier pigeons are scientifically designed and manufactured. Our common metals of to-day are purer than those commercially acceptable during or before the World War. It is debatable whether a new civilisation will arise that needs fewer minerals, but it is reasonable to suppose that the minerals that will be produced in steadily increasing quantities will be those that are cheap. Included as cheap are not only those that cost little per pound, but even those that are peculiarly efficient, of which a little goes a long way.

Wider Choice of Materials

As chemists grow more expert in the rearrangement of atoms, they have a wider choice of raw materials. The natural state of combination of the elements in nature will become less important. Under these circumstances, sulphur, for example, will be taken from the nearest source, whether it be brimstone, pyrite, gypsum, or smelter smoke. Magnesium is one of the most abundant elements; yet until recently magnesia refractories were made from Austrian magnesite almost exclusively. Later, other magnesite deposits were utilised, and about two years ago a company began making a synthetic product from sea-water. Nowadays, when magnesium or any of its compounds are wanted, there is the choice of magnesite, brucite, dolomite, sea-water, brine wells, and even various silicate minerals, including serpentine and olivine. This example is cited merely to show that modern industry is not bound to one source of a given material. Monopolies on ownership of unique mineral deposits are rare indeed, but where they do seem to exist they can generally be broken by chemical manœuvring. Moreover, man is adaptable; he will change his wants or find substitutes if any article costs too much. In the long run, the international movement of most minerals tends to decline, and the use of elements that are locally abundant and cheap tends to expand.

A wise philosopher has said that nothing is constant but change. One metal may be substituted for another, and both may gain or lose in the fight for markets with non-metallic materials. Some metals are light, others heavy; some strong, others weak. For structural purposes, especially in aircraft, lightness combined with strength is demanded. Iron is stronger than the same weight of aluminium, but by alloying iron to make steel, it becomes still stronger. Persistent research has turned the tables, however, and by alloying the light metals, aluminium and magnesium, and utilising a new technique of age-hardening, still newer alloys were made that were stronger than ordinary alloy steel. The race goes on in much the same way that the invention of a new armour plate speeds the development of new guns and projectiles, or vice versa. Cadmium rustproofing, after displacing galvanising, itself had to compete with improved pure zinc plating. Inter-product competition between mineral products is keen, but mineral products as a class generally have won over non-mineral products. In the broad field of manufacturing newly developed plastics are being used occasionally instead of metals, but it is significant that none of these synthetic products are processed without mineral raw materials, and that some of the newer ones are almost wholly of mineral origin.

An increasing flow of materials from farm and forest may be expected. We hear more and more about chemurgy, the growing of crops for industry. Agriculture has become so efficient that our farmers could produce as much food as they do now with half as many men and half as much land. Already most people in this country are fairly well fed, and the chances for increasing the consumption of food are definitely limited. No such limits are placed upon the consumption of manufactured goods, and if industry will use more farm products our farm problem finally may be solved. It does not follow, however, that the increased use of farm and forest products forebodes competition with minerals. In any event, mineral fertilisers and tools will be needed on the farms, and inorganic chemicals will be needed in the factories and processing plants.

This is an age of specialisation, but the student of markets for minerals must scan many fields. Experiments already are under way at the Massachusetts Institute of Technology to capture sunshine and use it for household heating and refrigeration, displacing coal or fuel oil. Only a year ago the hope was revived that soon we might be able to utilise atomic energy. News of splitting uranium atoms came as a surprise even to the physicists, and it still remains to be seen whether the limitless energy sealed in the atoms of terrestrial matter can be released for use as industrial power. It has been deduced that, by splitting its atoms, 8 lb. of uranium would afford enough energy to drive the biggest ocean liner across the Atlantic. The transmutation of elements, the alchemist's dream, is an accomplished fact. Should it prove commercially feasible to fabricate any metal merely by blasting it out of common elements, no metal need ever be called rare. Moreover, spectrographic analysis of rocks and minerals is demonstrating that many so-called rare elements are rare only in the sense that they are less abundant than the more common elements and not localised to the same extent in workable deposits. As more attention is given to recovering these rare elements as by-products, the variety of elements and their possibilities of application will be increased.

The increasing efficiency of mineral utilisation can be illustrated by a specific example. In the Great Wall of China, brass tubes were used to afford means of communication between guard stations. To-day, we send 100 telephone messages over a single wire and can even do without the wire. However, these accomplishments, while displacing no one knows how many brass tubes as a vehicle of spoken communication, have created a demand for a variety of other minerals. Not the least of these are the tiny slices of quartz that are needed to separate the messages. The quartz crystals from which these slices are cut are of a very special kind, so far found in reasonable quantity only in Brazil, and have the unique property known as piezo-electricity, that permits them to be used for frequency control in modern radio transmitters and telephone service.

New uses for minerals do not just grow. They have to be created, and ordinarily it is the producers who must find applications for their products. Research is forever at work to make better products, but the public must be told about the products and shown how to use them. One of the most frequently cited examples of research applied to market development is nickel. Nickel production soared during the World War, but peace-time uses were few. After 1918, however, the International Nickel Co. expanded its laboratories and proceeded to determine the real uses of its product. Aggressive research demonstrated new and better ways of using the metal, and to-day motor-car manufacturers consume 30 to 40% of the entire output of nickel, the railroads have become important buyers, and stainless steel and other alloys containing nickel are employed in countless places where no metals had hitherto been considered applicable. Nickel alloys with unusual electrical or

magnetic properties have been produced, and the metal is being employed in the chemical industries both to resist corrosion and as a catalyst. In 1930, when depression cut deep into income, the International Nickel Co. increased its spending on research by one-third, with the result that six years later its sales of nickel nearly doubled those of the best war year.

When platinum metals became an important by-product of nickel, this company proceeded to find more uses for them, and last year world consumption of platinum metals was around 500,000 oz., roughly twice as great as in any year before the research was begun. The demand for aluminium likewise has been created largely by the leading producers. The same may be said of markets for magnesium, molybdenum, vanadium, and several other metals.

Effect of Research

Research on the production and use of new metals and minerals necessarily keeps in close touch with the broad field of technical industrial research and the demands of industry. Some of the uses found for the rarer elements were glimpsed first by research workers employed by the telephone, radio, and electrical companies. Consumers' laboratories, in fact, constantly are seeking the best materials for specified purposes. Occasionally they may hit upon new uses for a material, but as a means of disposing of potential by-products the process of waiting for consumers to develop new demands unaided, is about as effective as waiting for lightning to start a camp fire.

Many minerals are either only partly used or not used at all. Rarely, indeed, does the discovery of new uses outrun supplies, and the threat of over-production has plagued the miner almost as much as it has the farmer. No one is ever fully satisfied with the demand for his product. Potential surpluses, however, do help to gain consumer acceptance for a new product. The beryllium industry, for example, undoubtedly would have grown much faster had prospective consumers been more sure of adequate reserves of ore in the ground.

Relative abundance in the earth's crust is only one indication of ample supply, for there are other factors, including the tenacity with which some elements cling to their chemical bonds and also the fact that many widely distributed elements are found only in minute percentages in rock masses and not concentrated in high-grade deposits. Many so-called new metals are new only in commercial extraction and utilisation, having been known to scientists for scores of years. The term " rare metals " often is a misnomer in so far as it may imply scarcity. Many persons would be surprised to learn that uranium, tungsten and lithium are more abundant in the earth's crust than is zinc ; hafnium and thorium, than lead ; and beryllium and rubidium, than tin. Antimony, a relatively cheap metal, ranks low in occurrence. Tellurium, although about as rare as platinum or gold, is a drug on the market, and only recently were uses found for even a small fraction of the tellurium available in metallurgical wastes.

The three most abundant elements in the earth's crust that are stable when isolated from their combinations are, in order, aluminium, iron, and magnesium. The rapid growth in production of the light metals, aluminium and magnesium, confirms the prophecy that eventually they will rival iron in industrial utility. Silicon, calcium, sodium, and potassium are even more abundant than magnesium, and although none of them except sodium is used so extensively in the metallic state, their compounds have great industrial importance. Rock salt and limestone, in particular, are so widely distributed and so easy to mine that it seems a pity that they are not utilised even more extensively in industry. Enormous quantities of salt water run to waste at oil wells, and inexhaustible supplies of sea water and other natural brine can be tapped at innumerable places. In addition to sodium and chlorine, these brines can be made to yield a great deal of magnesium, calcium chloride, and a host of minor constituents, of which only bromine is now extracted.

Commercial sources of magnesium or its compounds now include brines, magnesite, dolomite, brucite, carnallite, and kieserite. However, as previously stated, other minerals—notably olivine, serpentine, and talc—contain much magnesium, and they, too, may be utilised to a greater extent when the chemists tackle the job in real earnest. Next to magnesium, titanium is the most abundant metal ; it is half again as abundant as carbon. A fair amount of rutile is used for welding rod coatings, and titanium pigments have become important, but we go to British India for supplies of high-grade ilmenite, and no one seems able to utilise the tremendous deposit of lower-grade material, especially the titaniferous magnetites. Seemingly important uses have been found for zirconium compounds, but those who produce it as a by-product of rutile would be glad to discover additional markets.

The rare-earth metals, oddly enough, are not rare at all. There is doubtless more cerium in the world than there is mercury or antimony, and the probable supply of the group as a whole is greater than that of zinc, lead or several other fairly common metals. Nevertheless, so far the uses of the rare-earth elements have been confined to sparking flints, and, in the form of compounds, as minor constituents of special glasses. Tellurium is available in much larger quantities than are needed at present. Gallium, germanium, and indium are by-products of the zinc industry that could be recovered in relatively large amounts, but scarcely anyone outside of the laboratory seems to want them. Marked progress has been made in recent years in increasing the demand for chlorine, bromine, fluorine, and phosphorus, but natural supplies of these elements are so abundant that consumption could be increased manifold without threatening a shortage. Lithium and strontium deposits also are large enough to encourage the search for more uses.

The real test of an enterprise is whether it makes full use of its opportunities. Mine dumps, mill-tailing ponds, and metallurgical wastes present a perpetual challenge. One by one the minor elements found in smelter smoke and refinery sludge have been caught and put to work. Iron blast-furnace slags are made into cement or mineral wool. In thickly settled communities slag and rock waste are used for concrete aggregate and road construction. Waste slate, however, is not suitable for these purposes, and perhaps the most urgent problem of all is the need to balance demand against potential production of coal. Research on coal utilisation covers a broad field, ranging all the way from proposals for burning the coal in the ground (without mining it) to the manufacture of nylon, a synthetic fibre made from coal, air and water.

Alexander is said to have wept because there were no more worlds to conquer, but the research workers' field of action to-day is not so limited. Never before has man been so dependent on minerals, and never before were there so many opportunities to find new uses for them. It would be venturesome to predict which consuming industries afford the best opportunities, but apparently the minerals that will be the most successful in finding new applications in the future, even more than in the recent past, will be those that are abundant in nature and so can be produced at low cost.

Wire Dies Import Licensing

The licence permitting the importation of diamond and metallic carbide wire-drawing dies from any country without separate licence is withdrawn. Applications to import diamond dies should be completed in duplicate and addressed to the Diamond Dies Section, Non-ferrous Metals Control, Ministry of Supply, Grand Hotel, Rugby. Applications to import metallic carbide dies should be addressed direct to Import Licensing Department, Southampton Buildings, Chancery Lane, W.C. 2.

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Resources of the Empire

IN her struggle against an attempted world tyranny Britain is not alone, the other members of the British Commonwealth, including the self-governing dominions—Canada, Australia, New Zealand, and South Africa—have decided to fight shoulder to shoulder with Britain to overcome brute force and oppression. India, too, and the British Colonial Empire are contributing in no uncertain manner. This not only means support by men and machines, but the enormous contributions of mineral resources and raw materials of the Empire. For example, the whole exportable surplus of Canadian copper, zinc and aluminium has been bought by the Ministry of Supply. By far the greater part of Canada's output of copper has been contracted for, and the Ministry has arranged for a substantial increase in production of the Aluminium Company of Canada, sufficient to bring its total capacity near to Germany's pre-war total of 130,000–140,000 tons per year. Large purchases of Canadian lead have also been made.

Canada's output in minerals in 1939 reached the record total of $473,107,021. In that year output records were established for gold, copper, nickel, zinc, antimony, bismuth, and cadmium, and the recovery of platinum metals from Canadian nickel ores has further strengthened the position of the United Kingdom with regard to these valuable products. Although some decrease in the output of lead in that year was experienced, it amounted to nearly 400,000,000 lb. About 97% of this total came from the mines at British Columbia, of which by far the largest producer is the Sullivan. The total zinc output in that year also amounted to nearly 400,000,000 lb.

Canada occupies a prominent position among world producers of non-ferrous metals; she is, in fact, the world's largest exporter. She stands first in nickel and in platinum metals, which are derived almost entirely from nickel-copper ores. In the production of copper in all forms she ranks third; in mine and smelter output of lead she is surpassed in output only by the United States, Mexico, and Australia; while in output of zinc in all forms the Dominion was exceeded only by the United States, and in her output of refined metal by the United States, Belgium and Germany, during the last complete year for which figures are available.

Non-ferrous smelting and refining ranks first among Canadian manufacturing industries, and it is not surprising that the war has given a great impetus to her mining industry; it is safe to say that new high-production levels are being attained. But this is also true of Australia, from which Britain has bought all the exportable surplus of Australian copper, zinc, lead, and tungsten. The surplus of New Zealand wolfram is being purchased by the Minister of Supply, the same applies to the base metals mined in South Africa, and the chrome ore and tungsten from Southern Rhodesia.

One of the most important minerals is manganese, mainly because of its vital role in the making of steel. Over 90% of the consumption of this metal enters into steel manufacture, for which it can be regarded as indispensable. Before the war Germany was the second largest consumer of manganese, but her ore deposits amounted to very little, and by far the greater proportion of her requirements had to be imported. In 1937 52% of her manganese ore imports came from South Africa, and 22% from British India—a fact of considerable significance to-day. About 30 lbs. of high-grade manganese ore are consumed for every ton of steel produced, and no adequate substitute has yet been discovered; it is noteworthy, therefore, that Britain's supplies are obtainable from the resources of the Empire.

For some years passed considerable interest has been taken in the production of tungsten from Empire sources. In 1937 the British Empire produced about one quarter of the world's consumption. Burma is the most important Empire producer of tungsten ores, producing over 60% of the Empire's total output. The ore is essentially wolframite, and is usually obtained together with tinstone. Australia shows a big increase in production. The main developments have been in the northern territories and Tasmania. In the former, there is considerable activity in wolfram mining. Recent interest in tungsten has brought into operation an important source in north-western Otago, New Zealand. Old claims have been reopened and development work is in progress on new claims. Although a number of tungsten mines in Southern Rhodesia are still in the development stage, production in recent years has been appreciable, and recent months have seen greatly increased results.

Normally, neither Britain nor the Dominions exercise a monopoly of these resources, which would be detrimental to the rest of the world. In peace-time, these resources are available to other nations on the open market and at world prices. In war-time, however, they have become a vast reservoir upon which the members of the Commonwealth can draw and which are denied to the common enemy. These Empire mineral resources are, obviously, being directed to the successful prosecution of hostilities, and control of materials has been instituted in order to ensure adequate supplies for war work.

The adequate supply of metals, without which the struggle could not be carried to a successful conclusion, is only one aspect of the manner in which the overseas members of the British Commonwealth are contributing in fighting the disease of tyranny that stunts and kills the spirit of liberty. In addition to raw materials and food, the various nations are sending men and machines in increasing numbers, while at the same time building up armies and navies capable of taking up the onerous duties of patrol near their own shores. Many of them have organised and are rapidly developing factories for the construction of aeroplanes and for the manufacture of munitions. The leading industrial organisations of Canada, for instance, have a central organisation which is completing new plants for the construction of bombers, existing plants being inadequate to supply requirements. Aircraft constructed in Canada have, of course, been supplied to Britain since the early months of this year. Current shipyard orders include 64 patrol vessels and 26 mine-sweepers. Many of the former are now in commission, and all will be completed next year. Australia, also, is building anti-submarine craft for Britain, to the maximum of her shipyards.

Britain is the vanguard of the struggle, but gradually, with growing impetus, the weight and power of a united Empire behind her will increase the power of attack against the common foe. This, together with the faith which springs from the hearts of free men for a cause which is just and honest, will overcome the fanaticism and brutality of the Nazis.

Obituary

READERS will have learned with regret of the deaths of Sir Robert Abbott Hadfield, Bt., and Sir Harold Carpenter, both of whom devoted their lives to the advancement of metallurgy, and though their activities were widely separated, their loss to this country is irreparable. The deaths of these distinguished men have followed very closely upon those of Sir Oliver Lodge and Sir Joseph John Thomson, all outstanding men in their particular fields of scientific activity.

Sir Robert A. Hadfield, Bt.

Sir Robert Hadfield, chairman of Hadfields, Ltd., who passed away on September 30, in London, in his 82nd year, devoted the major part of his life to the advancement of scientific and practical metallurgy, and his inventive genius and successful research in steel-making, resulted in important discoveries of special steel which placed him in a position of eminence both at home and abroad.

Sir Robert was educated at the Sheffield Collegiate School, where he was successful in taking a number of prizes and scholarships. At an early age he showed that his interests had a scientific trend, and his father encouraged him in his experimental pursuits in every way, and provided him with a small experimental melting furnace. Much practical knowledge was thus gained at an early stage, while no time was lost in initiating him in the practical work of the business his father had established, on the site at present occupied by the Hecla works, in the year 1872, under the name of Hadfields Steel Foundry Co.

When only 20 years of age he founded and inaugurated the chemical and physical laboratories of his father's works at Attercliffe. Here began an eventful scientific life, which was to make him world famous as a metallurgist, and his inventive genius and successful research work in steel-making did much to place Sheffield in a position of ascendancy, both in regard to important discoveries of special steel and the provision of those steels in the markets of the world. He carried out the first systematic investigation of alloys of iron and manganese in 1882, when he invented the steel which carries his name. He showed that by increasing the manganese content beyond 2·5% the steel became seriously embrittled, and by increasing the manganese content above 7% an entirely new metal was produced, the alloy containing 12 to 13% manganese possessing greater hardness and toughness than had previously been believed possible in an alloy steel. This complete research can be regarded as the beginning of alloy steel research.

In the course of his career Sir Robert received practically every medal of the first significance which can be awarded by the steel and metallurgical associations in Great Britain, America and the Continent. For the invention of manganese steel the Institution of Civil Engineers conferred upon him the Telford Gold Medal in 1888. In 1899 he was elected Master Cutler of that ancient Cutler's Company of Hallamshire, Sheffield, dating from 1624. In the same year the Institution of Civil Engineers presented him with the George Stephenson Gold Medal for research in nickel-iron alloys. In 1902, a year of great advance in Sheffield, the Institution of Civil Engineers bestowed upon him the Howard Quinquennial Prize for scientific work in connection with new alloys of steel. In 1904 he was awarded the Bessemer Gold Medal by the Iron and Steel Institute, and the following year was elected President of that body.

In 1908 he was knighted, and the following year he was elected a Fellow of the Royal Society. In 1911 the University of Sheffield conferred the honorary degree of Doctor of Metallurgy upon him, and in the following year he received the honorary degree of Doctor of Science from the University of Leeds. He was elected President of the Faraday Society in 1914, and held the office in succeeding years with distinction until 1920.

Sir Robert was created a baronet in 1917. In 1925 he was made an "Officier" of the Legion of Honour, and Commander in 1937. He was elected a Member of the French Academy of Sciences in 1923, also an Honorary Member of the French Society of Industrial Chemistry. He also held the John Fritz Gold Medal, bestowed in 1921, the highest prize of its kind that America can offer. A further distinction was the election of Sir Robert as Foreign Associate of the Washington National Academy of Sciences in 1928. The University of Oxford bestowed upon him the honorary degree of Doctor of Science, and the Council of the Institution of Mechanical Engineers elected him an Honorary Life Member. The Railway Engineering Gold Medal of the Institute of Transport, and the Thomas Turner Gold Medal of the Birmingham University are among his awards. A still further honour was conferred upon him in the award by the Association des Ingenieurs de Liège of the Trasenster Medal and Diploma for 1938.

Sir Robert Hadfield occupying his accustomed seat in his workroom.

Sir Harold Carpenter

Sir Harold Carpenter died under somewhat tragic circumstances; he was found drowned on September 14 in a stream at Clyne Valley, Swansea, where, it is believed, he had fallen after a heart attack. He occupied the Chair of Metallurgy at the Royal School of Mines for more than a quarter of a century. Born early in 1875, Sir Harold was a direct descendant of Henry Cort, the inventor of the puddling process, and was a metallurgist whose reputation was not confined to Britain; his achievements in the field of metallurgy not only concerned scientific investigations, as he was also a teacher, administrator, organiser and director of research.

Educated at St. Paul's School, Eastbourne College, and later at Oxford, where he gained a first class in Natural Science in 1906, he was a Research Fellow and Demonstrator from 1898 to 1901 at Manchester University—then Owen's College—and, on the establishment of the National Physical Laboratory in 1902, he was appointed head of the chemical and metallurgical departments. After about four years he returned to Manchester University as Professor of Metallurgy, and in 1914 he took up a similar position at the Royal School of Mines.

Apart from the knighthood conferred upon him in 1929, he received many honours. He was elected Fellow of the Royal Society in 1918, and was president of many technical institutions, including the Institute of Metals, the Institution of Mining and Metallurgy, and the Iron and Steel Institute. He received the gold medal of the Institution of Mining and Metallurgy; the Carnegie and Bessemer medals of the Iron and Steel Institute; and only this year was awarded the Houda prize by the Japanese Metallurgy Society—the first foreigner to have received this award.

The Steam Ageing Test in Evaluating Zinc Alloy Pressure Die-Castings

By P. Mabb

Several years of satisfactory experience with the newer types of zinc alloys, produced under controlled conditions, have proved their merit, especially in die-castings, but to guard against the effect of contamination by impurities during the die-casting operations, some form of test is necessary. Steam ageing is known to discriminate between good and bad zinc castings, and a controlled form of test is discussed.

THE outstanding feature associated with zinc alloys as die-casting materials is the low casting temperature, and consequently die wear is negligible and tool maintenance charges are low when compared with those involved in the pressure die-casting of aluminium alloys. Additionally, owing to their narrow freezing range, the zinc alloys are very fluid, so that when pressure die-cast, they are capable of providing very clear profiles. Again, shrinkage is small, so that castings are produced free from "wells." By virtue of these points, and using the correct type of die-casting machine, zinc-base castings can be produced with an excellent surface which requires little subsequent mechanical finishing prior to plating or enamelling. It is not surprising, therefore, to find zinc alloys have attracted the attention of the majority of engineering industries. As a result, numerous alloys have been developed to suit specific needs, and these, while providing the aforementioned meritorious features, have not overlooked the desirable mechanical requirements. The tensile strength for the various zinc alloys ranges from 18 to 22 tons per sq. in., and the elongation of 2 in. acting length from 4 to 6%. These compare with an average tensile of 12 tons per sq. in. for the ordinarily employed die-cast aluminium alloys, and 3% elongation. Regarding impact strength, values from 12 ft.-lb. to 25 ft.-lb. Izod are obtainable in zinc alloys, as against something of the order of 4 ft.-lb. for the aluminium series.

Despite the fact that zinc alloys have been under consideration for pressure die-casting purposes for very many years, it is only during the last five years or so that they have become really established in engineering. The slow rate of adoption has been due to the disfavour with which they became regarded because of general failures from disintegration. This phenomenon was not for a long period understood, and it was not until the compilation of results from fundamental researches into the causes and the evolution of commercial means of elimination of undesirable impurities progressed to the stage of producing guaranteed industrial alloys, that the confidence of users could be established. The present position is that the origin of the early failures is very well understood, and that several years of satisfactory experience with the newer types of alloy produced under rigorously controlled conditions of refining, have proved their merit as a thoroughly sound metallurgical proposition. Briefly, the cause of the disintegration of zinc alloys was intergranular corrosion due to the presence of traces of cadmium, lead and tin impurities. The danger limit for each of these elements is of the order of 0·005%, which exceedingly low amounts are hardly estimable by ordinary chemical processes, and obviously demand something very special in the way of refining of ingredients and preparation of the alloys.

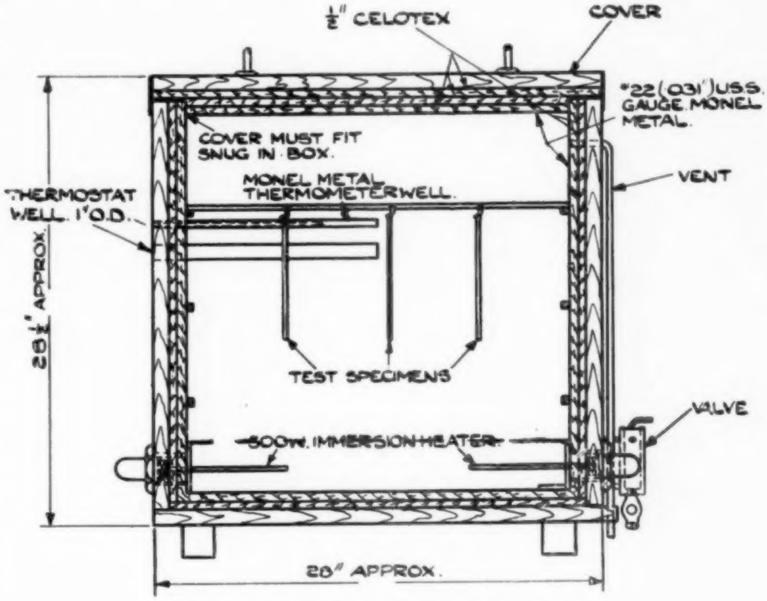


Fig. 1.—Typical tank for steam-ageing test

Alloys of the required degree of purity are marketed under the trade name of Mazak.

While alloys of the required degree of purity are available, it is evident that for conversion into components they have to be die-cast under normal industrial conditions by the usual die-casting specialist. It is therefore necessary for the user to adopt some means of satisfying himself that the die-castings are sound and that no contamination has crept in between ingot and component. Analysis can be adopted, but this involves either a highly specialised technique of electro-analysis or an equally skilled process of spectrographic analysis, neither of which, in the normal way, falls within the compass of the works laboratory. Fortunately, it has been found that steam-ageing, which for many years has been known to discriminate between good and bad zinc castings, can be employed, and a controlled form of test is now established. The disadvantage of this method of inspection is the lengthy time involved, but it is positively informative in so far as an agreed number of specimens can be tested from each batch, and examined dimensionally and visually before and after test.

The steam-ageing test comprises continuous subjection of the specimens to an atmosphere of 100% relative humidity at a temperature of 95° C. for a period of 10 days (240 hours). Not any form of humidity cabinet will suffice for this purpose. A metal-lined chamber, heavily thermally insulated, is essential. The humidity of the atmosphere is generated from a generous layer of water covering the bottom of the tank and in which are situated electrical immersion heaters. The latter have to be automatically controlled, but the controlling thermostat is situated in the atmosphere in which the specimens are suspended and alongside a thermometric indicator. A snug, well-fitting,

metal-lined lid closes the cabinet. Provision has to be made for automatic or manual replenishment of water and a vent provided to prevent pressure build-up. No wood or organic matter should be within the cabinet. Specimens should be suspended from glass or porcelain rods by means of zinc-coated steel wire. A suitable metal for the lining is copper or Monel metal. Obviously many forms of tank are possible in conformity with this specification, and a typical one is shown diagrammatically in section in Fig. 1.

In broad terms, the requirement of this test may be stated as follows :—

1. Dimensional changes should not be greater in any dimension of 1 in. or over than an increase of 0·001 in. per inch. Also, 0·001 in. maximum increase must be allowed on dimensions of less than 1 in. In view of the small amount of expansion that is permitted, it is important that measurements should be accurate, and exactly located for the two series of readings, before and after test. "Solid dimensions"—namely, those uninterrupted by holes or recesses, should be selected for acceptance inspection tests, although of course any linear dimensions may be chosen for informative studies on stability of particular casting designs.

2. Judged from visual examination, no evidence should exist of cracking, including the development of fine surface cracks, blistering, or laminating.

3. It is evident that the alloy, exposed to hot, moist air, will corrode, and after the test will exhibit an adherent whitish coating. Also, corrosion will penetrate and, examined in the cross-section, the specimens will reveal a black "corrosion-case." The depth of this case in copper-free alloys should be negligible.

4. Changes in mechanical strength under this test will occur to a degree dependent upon the actual composition of the alloy. In general, they cannot be determined upon components, but only upon test-pieces. However, it is not usual to inspect for this quality for acceptance purposes, reliance upon the nominal composition chosen, and satisfactory test results from 1, 2 and 3 above being adequate safeguard.

Choice of alloy is determined to some extent by specific requirements of the job. However, whenever best retention of mechanical properties and minimum dimensional changes with age are entailed, selection is restricted to the alloy conforming to Mazak No. 3. Mazak No. 2 is a general purposes alloy, while Mazak No. 5 is something of a compromise between Nos. 2 and 3, whereas Mazak No. 6 is the most easily castable alloy, and is suitable for application where permanence of physical and mechanical properties in the as-cast condition is not of prime importance.

Table I gives some typical steam-ageing test results on test-bars. In particular, it demonstrates how remarkably good these alloys are when cast without impurity contamination. Specimen No. 4 exhibits the greatest changes—namely, in loss of strength, dimensionally and with respect to depth of corrosion.

Table II deals with the steam-test results on a miscellany of commercial castings. Specimen No. 1 represents a satisfactory batch of castings, while No. 2 represents the same type of casting made from the same alloy, but the latter having been allowed to become contaminated through scrap additions. Specimen No. 3 represents a batch of castings made from a different class of alloy, the latter evidently badly contaminated with impurities, probably not from scrap additions but from impurities in the alloying elements. Specimen No. 4 falls in the same category, but with a much lower degree of contamination. Specimens Nos. 5 and 6 represent alloys containing copper, but free from contamination. A similar type of alloy is contained in No. 7, but in this case the alloy has been badly con-

TABLE I.

STEAM-AGEING TESTS ON PRESSURE DIE-CAST ZINC ALLOY TEST-BARS.

	No. 1.	No. 2.	No. 3.	No. 4.
Alloy Composition, %—				
Copper	1·9	1·9	nil	2·3
Aluminium	4·0	4·0	4·5	3·9
Tensile strength, tons/sq. in. as received	18·2	18·4	18·0	20·5
Elongation % on 2 in., as received	4·5	3·0	8·0	4·5
Tensile strength, tons/sq. in. after steam-ageing	15·8	14·9	16·0	13·7
Elongation % on 2 in. after steam-ageing	3·0	2·5	10·0	2·0
Dimensional changes due to steam-ageing, increase in inches on :—				
⅛ in. thickness	—	—	—	nil
⅛ in. width	—	—	—	nil
1 in. „	—	—	—	0·002
¼ in. diameter	—	—	nil	—
¼ in. square	0·0015	0·0015	—	—
Visual examination of surface and of fracture after steam-ageing	No evidence of laminations or of cracking on any sample, marked depth of penetration only in No. 4.			

TABLE II.

STEAM-AGEING TESTS ON MISCELLANEOUS PRESSURE ZINC ALLOY DIE-CASTINGS.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
Alloy Composition, % :—							
Copper	nil	nil	2·9	2·9	1·9	1·1	1·4
Aluminium	4·4	4·2	4·3	4·3	4·0	4·0	4·2
Dimensional Changes due to steam-ageing—							
Inches increase per inch of solid dimension	nil	0·002	Too distorted to measure.	0·0035	0·001	nil	—
Inches increase in thickness	0·002	0·004		0·0035	0·002	nil	—
Visual examination after steam-ageing :							
(a) Of surface	O.K.	Wide network of surface cracks. Laminating.	Wide network of surface cracks. Laminating. Distorting.	No cracks evident.	O.K.	O.K.	Cracked and fell to pieces.
(b) Of fracture	O.K.	Deep corrosion penetration. Strength nil.	Deep corrosion penetration.	Embrittled, deep corrosion penetration to a depth of 0·015 in.	O.K.	O.K.	Corroded through.

taminated. It is pointed out that Nos. 6 and 7 were of very thin cross-section (0·020 in.).

Most zinc alloy components have to be finished, and when organic finishes are entailed, sand or shot-blasting is popularly employed as a mode of surface preparation. There is always the argument that added distortion may occur thereby, due to removal of the skin of the casting. To ascertain the correctness of this assertion, a number of castings were dimensionally measured, avoiding "solid" dimensions and selecting those most likely to reveal distortion; half of them were then shot-blasted and the whole subjected to steam-ageing. Average test results are given in Table III, and they show that the effect of abrasive blasting small castings is without detriment to dimensional stability.

TABLE III.

INFLUENCE OF ABRASIVE BLAST (SAND OR SHOT) ON ZINC.BASE PRESSURE DIE-CASTINGS AS REVEALED BY STEAM-AGEING TEST.

Sample No.	Dimension, Inches.	Increase in Dimension in Inches.	
		Not Blasted.	Abrasive Blasted.
1	0·722	0·003	0·0015
	1·375	0·0025	0·0015
	0·249	0·003	0·002
2	1·373	0·004	0·0025
	1·402	0·001	0·0015
	0·723	0·002	0·0025
	0·249	0·0015	0·002

Table IV appertains to "finished" castings subjected to steam test. For the purpose, "bad" castings were selected —namely, those made from contaminated alloy and known to fail badly on steam-ageing. The conclusions to be drawn are that "finish" retards the deteriorating action of the test, and that if it is a "sound" finish, the retarding action is very marked. This stresses the point that "finished" castings should not be employed for the test when the object of the latter is to evaluate the casting. At the same time, the results do indicate that a sound finish affords additional protection, but this should not be used to offset the disadvantages of inferior castings.

In the above, it has been shown that the technology of zinc-base die-casting has advanced considerably and established itself as a commercial art. Fortunately, this has been established by a thorough understanding of the characteristics of the zinc alloys used and the determination of the harmful impurities. Guaranteed zinc alloys are available for the foundry. On the other hand, no obvious guarantee exists for the user that the foundry has used the right type of alloy or safeguarded against its contamination during casting. The steam-ageing test is a readily conducted method for the user to discriminate between good and bad.

TABLE IV.

INFLUENCE OF ENAMEL FINISH ON ZINC-BASE PRESSURE DIE-CASTINGS SUBMITTED TO STEAM-AGEING TESTS.

Condition.	Dimensions in Inches.		Appearance.
	Before.	Increase.	
Unfinished (as cast)	Too distorted to measure.		Badly distorted wide network of surface cracks. Laminating and fracturing. Deep corrosion penetration.
Stoved aluminium synthetic.	3·216	0·010	Slightly distorted, som esurface cracks, slight evidence of laminating.
Phosphated (Parker P.Z. or Granodine 31) and stoved aluminium synthetic.	1·316	0·010	Very little distortion, very few surface cracks or signs of laminating.

It is inexpensive to operate, but has the disadvantage of being relatively slow for routine inspection purposes. This is a shortcoming that has yet to be overcome. In the meantime, it is a procedure, but provides a reliable guarantee of performance. Moreover, the results are such that, providing the test is conducted as specified, cannot possibly give rise to dispute or differences of opinion.

Boron as a Component of Copper Alloys

INTEREST in the possibilities of boron as an alloying ingredient has only developed to the practical stage in quite recent years. Chromium borides and other boron and chromium-containing alloys formed the subject of a recent survey.* Copper alloys have likewise been the subject of recent investigation from the standpoint of the modifying action of boron. The novelty of this aspect is indicated by the fact that no mention of it is apparently made in such authoritative works as Carpenter and Robertson's "Metals" (1939) or "The Survey of Aluminium Bronzes," published by the Copper Development Association in 1938. The paucity of data in this field may be due in some measure to the early difficulties in the way of introducing boron into alloys. In the deoxidation of copper with calcium boride, for example, no boron is liberated to alloy with the copper. The high-melting point of elementary boron is an obstacle to its direct incorporation into other metals, even assuming it were available at a reasonable price.

It is now possible, however, to reduce boron from its compounds under conditions permitting it to alloy with copper. Briefly, the process consists in high-temperature reaction of a boron compound with an alloy of copper with magnesium, beryllium, or silicon.[1] The magnesium alloy (e.g., with 80% copper) is preferable on economic grounds, and the reaction takes place at a temperature of 1,200° to 1,350° C., when pure boron trioxide is the source of boron. The magnesium is removed as slag, and a copper alloy with 2 to 5% boron is finally obtained. This alloy is the most convenient form for introduction of boron into other copper alloys.

* *Metallurgia*, Vol. 22, No. 131, p. 148.

An important use of copper-boron alloys is in the improving of copper-zinc alloys, which are benefited in respect of welding, casting and brazing properties by addition of as little as 0·01 to 1% boron.[2] Among other factors, the amount of dross present governs the amount of copper-boron alloy to be used with a given batch—e.g., in the remelting of brass scrap. One function of the boron is to reduce the oxides present with formation of boron trioxide, which then acts as a flux. Sufficient copper-boron alloy must consequently be introduced to allow for this fluxing action while leaving a margin to allow a certain proportion of boron to alloy with the brass. Alloys made on these lines are recommended for such purposes as welding rods, brazing solders, and electrical contacts.

Boron has been found to replace phosphorus with advantage in copper-tin alloys.[3] Excellent as are the mechanical qualities of phosphor bronzes, the same cannot be said of their electrical conductivity. This defect shows up when using phosphor bronze for current-carrying springs. Again, the low melting point of the phosphorus eutectic is partly responsible for the hot-shortness of phosphor bronzes. Boron bronzes, on the other hand, possess excellent electrical as well as mechanical properties and can be easily hot-worked. As in the case of brasses, some allowance must be made for the deoxidising action of boron when introduced in the form of its copper alloy. An alloy content of 0·05% boron is recommended for an alloy with 10% tin, while a bronze intended for hot-rolling should be remelted with enough boron alloy to give a final product containing at least 0·1% boron.

1 H. F. Silliman and American Brass Company, U.S.P. 2,195,433 (1940(.
2 H. F. Silliman and American Brass Company, U.S.P. 2,195,434.
3 H. F. Silliman and American Brass Company, U.S.P. 2,195,435.

The Electrogalvanising of Wire

Recent developments in electrogalvanising steel wire are discussed and reference made to some of the chief problems encountered. The Bethanising and Meaker processes are briefly considered. Compared to hot-galvanised wire, electrogalvanised wire is expected to have longer life due to greater uniformity of coating as well as to heavier coatings available.

RECENT progress in electrogalvanising round steel wire has resulted in the installation of several large plants. Two processes are in use: that known as the Tainton or "Bethanising" process, for which the zinc is obtained directly from the ore; and that known as the Meaker process, in which zinc is introduced into the bath through pure zinc anodes. In the former process the bath contains sufficient acid to permit high current densities, while in the Meaker process the bath is nearly neutral but contains addition agents for this purpose. Some of the early electrogalvanising wire installations and the difficulties encountered have previously been discussed,[1] the chief problems may be summarised as: limitations of current density, and therefore of speed of coating; and difficulties in cleaning the steel wire adequately to obtain adhesion of the zinc coatings. In addition to these there were other technical problems, as well as commercial considerations, which held back the development of the electrogalvanising process for wire. Ernest H. Lyons, Junr.,[2] discusses some of these problems, and suggests that the difficulty in cleaning is the result of decomposition of drawing compounds due to elevated temperatures and pressures during drawing. Traces of copper may lead to hydrogen occlusion and brittle coatings, and iron salts contaminate coatings with iron.

The most interesting feature of these electrogalvanising processes for wire is the high current densities at which zinc is deposited. These high current densities can be used because: (1) there are no edges or corners resulting in excessively high, localised current densities; (2) concentration polarisation is reduced since the wire is agitated by the inevitable "strumming" effect as it is drawn at high linear speed through the electrolyte; (3) the solutions contain acid or other additions which maintain a good deposit at high current densities.

Wire electrogalvanised by the new processes has not yet been in service long enough to show its service life; however, the condition of test samples at present confirms the anticipated advantages as far as can be seen. Its use for woven wire fence, poultry netting and barbed wire is already important, and large quantities have been employed for telegraph and telephone lines. It is manufactured into hundreds of articles such as pail bales, hose clamps, coil springs, crimped and woven screen, tyre wire, submarine cables, box bindings, revetment mats and bed springs. There are growing tendencies to use it in place of tinned wire for certain applications, for bale ties, packaging, and for certain structural purposes.

Advantages of Electrogalvanised Wire

Many have supposed that electrodeposited zinc coatings would corrode less rapidly than hot-dip coatings, since the latter invariably contain a certain amount of iron which might serve as a corrosion promoter, as most impurities do. The evidence is still insufficient to decide this question and, indeed, it may never be decided, since variations in the corroding atmosphere appear to exceed variations between the coatings, and many contradictory results have been obtained. Yet it seems safe to say that any difference which may exist between the corrosion resistance of the two types of coatings, hot-dip *v.* electrogalvanised, is small compared with the effect of varying thickness or weight of coatings. If electrozinc has an advantage in this respect, it is probably less than 10% under most conditions.

Electrogalvanised wire, however, shows a uniformity unapproached by hot galvanising. Samples taken every 100 ft. along a mile of wire showed less variation than the accuracy of the strip test used—that is, less than 1%. Likewise, around the circumference the thickness varies less than the accuracy of the tests that might be applied, 3—5%. On the other hand, the thickness of hot-galvanised coatings on wire may vary 50% or more, especially in heavier coatings. Thus, for an equal average weight of coating, hot-galvanised wire often shows spots where the coating is much thinner than that of the electrogalvanised wire. These spots are points of weakness since it has been shown that the protection afforded is roughly proportional to the thickness of zinc coating.

A second advantage of electrozinc coatings is the unlimited thickness possible. Coatings as heavy as 4 oz./sq. ft. (0·12 g./cm.^{2}) have been deposited. In this way the life of galvanised wire in average exposures may be extended almost indefinitely. The hot-dip process is limited to coatings of about 1·2 oz./sq. ft. (0·037 g./cm.^{2}). The use of heavily galvanised wire is growing. In general, the life of the wire should be adjusted to that of the associated apparatus, such as the poles of a telegraph line, because in many cases the cost of the wire is overshadowed by the cost of erecting it. This can be achieved, in general, only with electrogalvanised wire.

A third advantage is the adhesion and ductility of the electrozinc coatings. Hot-galvanised coatings are subject to cracking and spalling on bending or forming, probably due to the more or less brittle iron-zinc alloy next to the steel surface. Electrogalvanised wire may be bent even until the steel is fractured without cracking or breaking the zinc coating. With some care it is even possible to break the steel while a small section of the coating remains intact, acting as a small hinge between the two pieces of steel. Such adhesion allows severe forming in manufacture or use. The wire may be rolled flat or drawn down in size without injuring the zinc coating, although its thickness is, of course, reduced proportionally to the increase in surface.

Experience has shown some advantage over hot dipping in the cost of electrogalvanising for light and medium coatings; heavy coatings are not produced by the hot-dip method. Against this must be set the substantially greater investment in equipment which is required. The physical properties of the steel are unchanged in electrogalvanising. High-carbon wire retains its hardness and strength, while low-carbon wire may be coated with equal ease and success in the same machine and even at the same time.

As coating thicknesses are controlled accurately and exactly by the speed of the wire and the electric current applied, shifts to different sizes of wire or different weights of coating require only a few adjustments of rheostats. The plant may be shut down in a few minutes, will "stand without attention," and can be started again almost as readily, in contrast to the requirements of hot-dip kettles. Electrogalvanising plants also are cleaner in operation.

Electrogalvanising does nevertheless possess some disadvantages. The process is new, and as compared to the century-old hot-dip method, much remains to be learned before its full flexibility and ease of operation are secured. The cost of the equipment is considerably higher than that required for hot-dipping. In a few instances the softness of the electrozinc has been a disadvantage. While it is possible to regulate the plating solution and conditions so as to obtain a somewhat harder coating, this has not yet been done in practice. With very fine wires the conductivity is so low as to limit materially the current density and speed of coating. However, methods to overcome this objection have been developed.

1 A. Weisselberg, Iron Age 137, 34 (1936); E. H. Lyons, Junr., Iron Age 138 47 (1936).

2 Electrochemical Society paper, presented at Ottawa, October, 1940. (Advance Copy.)

The Influence of Some Special Elements upon the Strain-Ageing and Yield-Point Characteristics of Low-Carbon Steels

Results are given of an investigation on the influence of varying percentages of different elements upon the strain-ageing characteristics of low-carbon steels. The elements included those that show little tendency to combine with carbon present in the steel and those that show definite tendencies to form carbides, and it is found that the former increase and the latter diminish the extent of strain-age-hardening of low-carbon steels.

THE influence of carbon, aluminium, copper, nickel, molybdenum, manganese, chromium, vanadium, niobium and titanium upon the strain-age-hardening properties of low-carbon steels has been investigated, and the work is described by Dr. C. A. Edwards, D. L. Phillips, and H. N. Jones.* It is a natural extension of the investigation dealing with the strain-age-hardening of mild steel, published a short time ago by Edward, Jones and Walters.† In this latter investigation the measure of the age-hardening capacity was taken as being indicated by the extent to which the yield points and ultimate-stress values were raised after straining and ageing. From the evidence obtained it was concluded that oxygen does not appear to play any direct part in the strain-age-hardening capacity of ordinary mild steel, at least so far as that quality is revealed by a rise in the yield point or ultimate breaking stress. It was shown that a steel containing an appreciable quantity of aluminium, and, therefore, presumably no "active" oxygen (i.e., free to combine with iron), displayed the same tendency to strain-age-harden as all the other samples that were examined.

In the present investigation it was decided to examine the influence of varying percentages of different elements upon the strain-ageing characteristics of low-carbon steels. For various reasons a constant degree of strain before ageing was used instead of the amount of strain which normally occurs at the yield point. In this way the results gave a more direct indication of the effects of the different elements upon the capacity for strain-age-hardening. The extent of this preliminary straining before ageing was 6·0% permanent elongation. This percentage was selected because it was large enough to be more than that likely to be produced at the yield stress for any of the specimens with which the authors would be dealing. In all cases the temperature of ageing was 250° C. The results of the tensile tests shown in the accompanying tables are the averages of at least two determinations for each set of conditions.

Samples containing varying quantities of the following elements were examined. A limited number of samples containing titanium, along with one of the above-mentioned elements was also used. In addition to the main object of the work, tensile properties of all the materials used, in the fully annealed condition, were recorded. Throughout the investigation the tensile properties were calculated on the basis of the original cross-sectional area of the specimen for both the annealed and the strain-aged conditions. In other words, no account was taken of the reduction in the diameter of the specimens due to the straining before ageing. In this way it was found easier to gauge the precise effects of strain-ageing.

* Paper presented to Iron and Steel Institute. 1940. Advance copy, 24 pp.
† *Jour. Inst. Iron and Steel Inst.* 1939. No. 1, p. 341

TABLE I.—ALUMINIUM STEELS.

	(*a*) Fully Annealed.						(*b*) After Straining 6% and Ageing.			
Aluminium %.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Stress for 6% Strain. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.	Crystals per Mm.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Ultimate Stress. Tons per Sq. In.	General Elongation.
0·02	11·92	2·88	15·91	19·79	31·8	35	19·13	2·33	21·86	15·3
0·25	11·82	2·64	15·85	20·04	24·3	36	19·19	2·25	21·88	13·5
0·57	11·98	2·44	16·36	20·46	26·9	32	19·35	2·00	22·40	14·6
2·25	12·08	1·23	18·05	23·00	25·0	15	21·05	2·04	25·36	12·9
3·40	16·10	0·85	22·74	26·94	19·7	13	25·58	2·25	29·92	12·2

Elements which do not combine with Carbon

Aluminium Steels.—For the examination of the influence of aluminium, five samples of the following compositions were made :—

		No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Carbon........	%	Under 0·025				
Manganese	%	0·26	0·23	0·28	0·25	0·26
Aluminium	%	0·02	0·25	0·57	2·25	3·39
Copper........	%	0·09				
Nickel	%	0·09				
Sulphur	%	Under 0·023				
Phosphorus	%	Under 0·010				

Steels Nos. 1 and 2 were annealed by heating to 950° C. in a nitrogen atmosphere for 1 hour ; steels Nos. 3, 4 and 5 were annealed at 1,050° C. in argon, followed by slow cooling. The results obtained from specimens in the fully annealed condition are recorded in Table I (*a*), and those obtained after straining and ageing are stated in Table I (*b*). There is not much difference in the extent of age-hardening for any of the specimens, so far as this quality is revealed by the yield point after ageing minus the stress required to produce the strain before ageing. With regard to the effects of strain-ageing upon the ultimate breaking stress, the results are much the same—an increase of, say, 2·0 tons per sq. in. for specimens containing up to 0·57% aluminium, rising to approximately 3·0 tons when 3·4% of aluminium is present.

Copper Steels.—Only three casts were specially made with varying copper contents, but the first sample of the manganese series can be regarded as filling the place of a low-copper sample for this series. The chemical compositions of the four samples were as follows :—

		No. 1.	No. 2.	No. 3.	No. 4.
Carbon........	%	Under 0·025			
Manganese	%	0·26	0·27	0·31	0·24
Copper........	%	0·09	0·27	0·60	2·97
Nickel	%	0·09			
Sulphur	%	Under 0·023			
Phosphorus	%	Under 0·010			

The results of the tensile properties in the annealed condition are shown in Table II (*a*), while the figures after straining and ageing are given in Table II (*b*). The difference between the initial yield points and the stress required to give 6·0% strain falls from 4·98 tons per sq. in., with 0·27% of copper to 2·75 tons when 2·97% of copper is present. The strain-ageing influence upon the yield point is 3·2 tons per sq. in. in each case, with the exception of the one with the highest copper content, for which it was

4·14 tons per sq. in. With regard to the effect of strain-ageing upon the ultimate stress values, this is practically constant when the copper is between 0·27 and 2·97%, and corresponds to a hardening equal to about 3·75 tons per sq. in.

Nickel Steels.—For the purpose of estimating the influence of nickel only two casts were specially made. These had the following compositions :—

		No. 1.	No. 2.
Carbon	%	Under 0·025	
Manganese..........	%	0·29	0·31
Nickel	%	0·60	1·61
Copper	%	0·09	

The results for the annealed and the strained and aged specimens are given in Table III (*a*) and (*b*). Curves show that nickel has a greater effect on the yield point after ageing than either aluminium or copper. Its effect on the ultimate stress is less than that of copper, but greater than that of aluminium.

Elements which Combine with Carbon

Aluminium, copper and nickel do not give rise to the formation of carbides when present in steel. Elements which are known to form carbides were next examined, namely, manganese, molybdenum, chromium, vanadium, niobium and titanium. There are wide differences in the intensities with which these elements combine with carbon when present in steels. In some instances they are known to share the carbon with the iron, giving rise to a mixture of two carbides, and even then the added element is only partly present as carbide and is partly dissolved in the ferrite solid solution. This is certainly what happens with manganese ; in the case of chromium, however, there are reasons for believing that very little, if any, chromium is dissolved in the ferrite, so long as its amount does not exceed that required to form $Cr_3C_2 + Fe_3C$, or CrFeC. It is expected that one of the remaining elements would possess a still greater affinity for carbon and possibly be capable of preventing the formation of any carbide of iron, without the need for much of the special element in excess of that required for combination with the carbon.

Molybdenum Steels.—Two casts containing molybdenum were made, which had the following compositions :—

		No. 1.	No. 2.
Carbon	%	Under 0·025	
Manganese	%	0·20	0·18
Molybdenum........	%	0·31	1·98
Nickel	%	0·09	
Copper	%	0·09	

The results are recorded in Table IV. Apart from the fact that both specimens give relatively high figures for the stress required to produce a permanent strain of 6·0%, the results call for no special comment. They both show strain-age-hardening to quite a marked degree ; this is evident in both the yield points and the ultimate stress values.

Manganese Steels.—In order to examine the influence of manganese, four samples were made. They had the following chemical compositions :—

		No. 1.	No. 2.	No. 3.	No. 4.
Carbon........	%	Under 0·025			
Manganese	%	0·26	0·50	0·93	1·90
Copper........	%	0·09			
Nickel	%	0·09			
Sulphur	%	Under 0·023			
Phosphorus....	%	Under 0·010			

The tensile properties of these materials in the fully annealed condition are recorded in Table V (*a*), and data

TABLE II.—COPPER STEELS.

	(*a*) Fully Annealed at 950° C. in Argon.						(*b*) After Straining 6% and Ageing.			
Copper, %.	Yield Point. Tons per Sq. In.	Yield Strain, %.	Stress for 6% Strain. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	General Elongation, %.	Crystals per Mm.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.
0·27	12·52	2·31	17·50	21·10	24·3	35	20·62	1·96	24·88	12·9
0·60	14·48	2·70	19·02	22·59	23·8	47	22·25	2·13	26·29	12·8
2·97	21·50	3·77	24·25	26·91	17·7	77	28·39	3·32	30·75	11·0

TABLE III.—NICKEL STEELS.

	(*a*) Fully Annealed at 950° C. in Argon.						(*b*) After Straining 6% and Ageing.			
Nickel, %.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Stress for 6% Strain. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.	Crystals per Mm.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.
0·60	14·80	3·31	18·53	22·58	24·2	63	22·77	2·87	26·00	11·6
1·61	18·16	4·13	20·76	24·51	23·7	90	25·38	3·27	28·15	11·8

TABLE IV.—MOLYBDENUM STEELS.

	(*a*) Fully Annealed at 1,000° C. in Argon.						(*b*) After Straining 6% and Ageing.			
Molybdenum, %.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Stress for 6% Strain. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.	Crystals per Mm.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.
0·31	11·67	2·06	17·33	21·24	24·6	33	20·70	2·04	24·78	13·2
1·98	14·75	2·15	20·03	24·23	23·4	35	23·44	2·00	27·52	12·8

TABLE V.—MANGANESE STEELS.

	(*a*) Fully Annealed at 950° C. in Nitrogen.						(*b*) After Straining 6% and Ageing.			
Manganese, %.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Stress for 6% Strain. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.	Crystals per Mm.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.
0·26	12·31	3·20	16·01	20·05	24·4	27	19·28	2·13	23·22	12·6
0·50	12·93	2·96	16·40	20·94	27·4	27	20·09	2·42	23·73	14·2
0·93	13·24	2·66	17·36	21·99	25·6	32	20·68	2·16	24·21	14·1
1·90	18·08	2·61	22·22	26·40	21·6	60	25·90	3·12	28·20	8·5

TABLE VI.—CHROMIUM STEELS.

	(*a*) Fully Annealed at 950° C. in Argon.						(*b*) After Straining 6% and Ageing.			
Chromium, %.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Stress for 6% Strain. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.	Crystals per Mm.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.
0·076	12·18	2·56	16·52	20·67	25·6	35	20·00	2·21	23·82	13·0
0·56	10·87	2·42	14·99	19·19	25·7	30	18·16	2·00	21·32	13·4
1·15	10·86	2·54	15·12	18·96	25·8	37	17·01	1·58	19·78	19·0
3·10	11·23	2·32	15·97	19·80	24·2	37	17·81	1·50	20·65	15·7
6·10	7·32	0·36	18·25	22·65	23·4	37	—	—	22·52	17·5

TABLE VII.—VANADIUM STEELS.

	(*a*) Fully Annealed at 1,000° C. in Argon.						(*b*) After Straining 6% and Ageing.			
Vanadium, %.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Stress for 6% Strain. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.	Crystals per Mm.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.
0·26	10·21	2·29	14·99	18·92	28·1	23	17·63	1·83	21·14	15·5
0·55	9·69	1·67	15·81	19·78	27·1	29	16·58	1·46	19·80	17·8
0·69	6·80	0·48	15·71	20·01	23·9	33	16·24	0·96	20·03	18·0

TABLE VIII.—NIOBIUM STEELS.

	(*a*) Fully Annealed at 1,000° C. in Argon.						(*b*) After Straining 6% and Ageing.			
Niobium (Tantalum), %.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Stress for 6% Strain. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.	Crystals per Mm.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.
0·28 Nb 0·05 Ta	7·49	0·50	15·74	19·47	24·3	16	17·03	1·37	20·01	14·3
0·36 Nb 0·06 Ta	—	—	16·32	20·52	26·2	27	—	—	20·36	19·7

relating to the effects of straining and ageing in (*b*). The yield points after ageing were just as clearly defined as they were in the original annealed condition. The difference between the new yield points and the stresses required to produce the 6·0% strain varies very little, and as these differences are not in direct accord with the manganese percentages, it would seem that this element, within the limits of 0·26 and 1·90%, is without influence upon strain-ageing so far as the yield points are concerned.

The position is not the same when the data for ultimate breaking stresses are examined, for, as will be observed from the figures in Table V, there is quite a noticeable decrease in the extent of the age-hardening as the manganese content is raised. For example, the hardening is represented by 3·17 tons for the specimen containing 0·26% of manganese, a figure which becomes progressively less as the manganese increases up to 1·9%, when the ultimate stress in the strain-age-hardened condition is only 1·8 tons higher than that of the annealed material.

Chromium Steels.—To study the influence of chromium, five casts of the following compositions were made :—

		No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Carbon	%			Under 0·025		
Manganese	%	0·23	0·29	0·29	0·29	0·29
Chromium	%	0·076	0·56	1·15	3·10	6·10
Nickel	%			0·09		
Copper	%			0·09		
Sulphur	%			Under 0·023		
Phosphorus	%			Under 0·010		

The results are presented in Table VI. There is a drop in the initial yield point of a little over 1 ton per sq. in. as the chromium content is raised from 0·1 to 0·56%, after which there is very little change until the chromium is increased from 3·10 to 6·10%. At this stage there is a marked drop, namely, from 11·23 to 7·37 tons per sq. in. There are only small variations in the stresses required to give a permanent strain of 6·0% in the first four members of the series, but a large difference in the case of the one containing the highest chromium. Further, Table VI indicates that, as regards both the yield point and the ultimate-stress values, there is a pronounced decrease in the amount of strain-age-hardening in each case when the chromium content is above 0·56%. This tendency is greater when 6·1% of chromium is present ; in other words, this last steel does not strain-age-harden. In this instance no clearly defined yield point was evident in the annealed or in the strained-and-aged conditions, the stress-strain diagram being very similiar to that of a non-ferrous metal or alloy. It is thus evident that the age-hardening, which for the time being is presumed to be due to the presence of carbon, can be neutralised by chromium, and that this effect is associated with the disappearance of the yield point. It must be admitted, however, that far more chromium was required to eliminate the yield point and prevent the material from possessing strain-age-hardening qualities than is needed to form Cr_3C_2 with the 0·02% of carbon present. It seems probable that the whole of the carbon cannot combine with chromium unless there is a substantial excess of chromium present. Under these conditions the character of the ferrite must be changed by the solution of chromium in it.

Vanadium Steels.—The next element considered was vanadium ; three casts were made having the following compositions :—

		No. 1.	No. 2.	No. 3.
Carbon	%		Under 0·025	
Manganese	%	0·30	0·32	0·26
Vanadium	%	0·26	0·55	0·69
Nickel	%		0·09	
Copper	%		0·09	
Sulphur	%		Under 0·023	
Phosphorus	%		Under 0·010	

The results are recorded in Table VII. Part (*a*) of the table indicates that the strain-age-hardening, as measured by either the yield point or the ultimate-stress values, is low in the sample containing 0·26% of vanadium ; it becomes even less with 0·55% of vanadium, and is absent with 0·69%. In the sample containing 0·69% of vanadium no real yield point could be detected on the stress-strain diagram. The smaller quantity of vanadium required, as compared with chromium, to bring about these changes in the properties is probably due to the much stronger affinity of vanadium for carbon.

Niobium Steels.—In this instance only two samples were made, having the following compositions :—

		No. 1.	No. 2.
Carbon	%	Under 0·025	
Manganese	%	0·21	0·25
Niobium	%	0·28	0·36
Tantalum	%	0·05	0·06

Unfortunately the ferro-alloy used for the purpose of introducing the niobium contained an appreciable amount of tantalum. There is, therefore, some uncertainty as to the extent to which the observed changes can be attributed to either one or the other of these elements. However, attention having been drawn to this doubt, it is proposed to regard the effects as being due to niobium. The results given in Table VIII indicate that 0·28% of niobium materially diminishes the intensity of the yield point and decreases the degree of strain-age-hardening as regards the rise in both the yield point and the ultimate stress. Further, in the sample containing 0·36% of niobium, no yield point was observed either in the annealed condition or after straining and ageing. The difference in the ultimate stress after straining and ageing is so small as to be within the range of experimental error.

Titanium Steels.—To examine the influence of titanium, two samples of the following compositions were made :—

		No. 1.	No. 2.
Carbon	%	Under 0·025	
Manganese	%	0·23	0·30
Titanium	%	0·085	0·21
Nickel	%	0·09	
Copper	%	0·09	
Sulphur	%	Under 0·023	
Phosphorus	%	Under 0·010	

The results are given in Table IX. There is quite a marked age-hardening effect in the sample containing 0·085% of titanium, but none in that containing 0·21% ; for the latter no yield point could be detected on the stress-strain diagram. Thus it is evident that only a small percentage of titanium—something between 0·085 and 0·21%—is necessary to prevent strain-age-hardening, on the one hand, and to cause the material to show no yield point, on the other. This is thought to be due to the titanium combining with the whole of the carbon present and forming an inert carbide of titanium. In all probability this carbide is insoluble in ferrite, and it would seem that a comparatively small excess of titanium need be present to ensure that the whole of the carbon will combine with it. It is also possible that the presence of titanium prevents the carbon which may be dissolved in the ferrite from being precipitated as a result of straining and ageing. In other words, carbon when associated with titanium and dissolved in ferrite is not precipitated.

Miscellaneous Alloys Containing Titanium

It was thought interesting to extend the research to a study of the influence of titanium in the presence of more carbon than had been dealt with so far, and also of the effect of titanium in the presence of other elements, such as copper and nickel, which appear to increase the strain-age-hardening capacity. Two carbon-titanium samples were investigated containing 0·085 and 0·095% carbon and 0·20 and 1·08% titanium, respectively, and it was found that, as the carbon increases, a relatively larger proportion of titanium is required to suppress the strain-age-hardening qualities of steel.

TABLE IX.—TITANIUM STEELS.

	(a) Fully Annealed at 1,000° C. in Argon.						(b) After Straining 6% and Ageing.			
Titanium. %.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Stress for 6% Strain. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.	Crystals per Mm.	Yield Point. Tons per Sq. In.	Yield Strain. %.	Ultimate Stress. Tons per Sq. In.	General Elongation. %.
0·085	10·96	2·08	16·04	19·88	26·1	25	18·69	1·87	21·99	13·5
0·21	—	—	15·35	19·37	26·1	19	—	—	19·34	23·2
The latter non-ageing steel was cold-drawn and low-temperature annealed to produce small crystals.										
0·21	6·92	0·42	—	20·96	28·4	—	—	—	—	—
0·21	7·21	0·42	16·54	—	—	—	16·35	0·42	20·96	21·2

In order to obtain evidence whether the addition of titanium in alloys containing copper would prevent this strain-age-hardening from taking place, two alloys, one containing 0·20% and the other 0·27% of titanium, and both containing 0·6% of copper, were made. The sample containing 0·20% of titanium gave a clear indication of strain-age-hardening, but this was much less marked in the corresponding copper alloy containing no titanium. The sample containing 0·27% of titanium showed no real yield point and no change of properties as a result of ageing after straining. Titanium was introduced into a low-carbon nickel alloy to determine whether it would have the same effect as it had in the copper steels mentioned. An alloy containing 1·61% nickel and 0·26% of titanium was prepared, and the results indicate that the addition of titanium produced a steel which had only a small yield point and gave very little indication of strain-age-hardening. Indeed, by loading at a constant rate no yield point was detected, and the ultimate stress-age-hardening was within the range of experimental error.

Crystal Size

In view of the well-known influence of crystal size upon the mechanical properties of metals and their alloys, and the possibility of there being some connection between the degree of strain-age-hardening and the mechanical properties of mild steels, representative samples of each composition were examined, and the size of the crystals present was estimated. For this purpose micrographs of fully-annealed specimens were used. The results, expressed in terms of the number of crystals per linear millimetre, have been plotted against the corresponding compositions of the different series. On comparing these curves with those for the yield points and ultimate-stress values many features of similarity are noticed, but the relationship is not complete.

From an examination of the crystal-size curves and a comparison of curves showing the effects of ageing after straining 6%, no rule applicable to all cases can be formulated. For example, in the cases of nickel and copper the degree of strain-age-hardening in members of each particular series is about the same, but there is a very substantial decrease in the size of the crystals as the percentage of each of the elements present is raised. In the manganese series, on the other hand, the maximum strain-age-hardening diminishes as the manganese is increased, but the size of the crystals decreases. With aluminium there is an increase in the maximum strain-age-hardening, but the size of crystal present increases as the amount of aluminium becomes greater. In the chromium series there is a marked decrease in the capacity of the steel to age-harden as the chromium content increases, and this becomes zero with 6·0% present, but the size of the crystals throughout the series remains practically constant.

The effects of the carbide-forming elements in reducing the strain-age-hardening qualities of steel seem thus not to be due to the presence of large crystals. In further support of this it is only necessary to refer to the results for the sample containing 0·20% of titanium with 0·02% of carbon. A piece of this material was heavily cold-drawn and low-temperature annealed to give very small crystals. Even after this treatment there was no change in the maximum-stress values after straining and ageing.

Stress-Strain Diagrams

The authors give a brief description of a limited number of typical stress-strain diagrams from amongst the large number which were taken during the present work. Two curves are shown for the first number of the manganese series, containing 0·26% manganese, and no other added element, one for the annealed specimen, and the other after straining and ageing. In both curves there is a clearly-defined yield point, and in the annealed state this corresponds with an elongation of 3·20%. Two curves from the steel containing 6·10% of chromium are also given. In the fully-annealed state there are only traces of a break in the curve, but nothing in the nature of a real yeild point. There is no yield point after strain-ageing, and no age-hardening as revealed by the ultimate breaking stress. The curves for the steel with 0·085% of titanium, indicate well-defined yield points and marked age-hardening after straining. The curves for the specimens containing a still higher percentage of titanium, namely, 0·21%, give no indication of a yield point, either in the annealed state or after strain-ageing, and there is no difference in the breaking stress of the two. The character of the curves is quite different when the carbon content is higher, even though the titanium content is the same as that just mentioned. Curves are given for the two steels containing 1·61% of nickel, one of them with no titanium and the other with 0·26% of that element. There is a very marked yield point corresponding to 3·27% elongation with no titanium present, but no yield point in the specimens containing titanium.

In the light of certain facts and the evidence which has been revealed in the present investigation concerning the influence of titanium and other carbide-forming elements in causing steel to become non-strain-age-hardening and in eliminating the yield point, the problems under review become much clearer. The position may be briefly summarised, as follows :—

The presence of small percentages of carbon, when associated with iron (i.e., not in combination with some other element), will give rise to strain-age-hardening.

The yield point, a characteristic of ordinary mild steel, is not an intrinsic property of iron itself, but is due to the presence of carbon.

The effects of carbon, as regards both its influence upon strain-age-hardening of mild steel and upon the yield point, can be completely neutralised by the addition of elements for which carbon has a greater chemical affinity than it has for iron.

The function of titanium and other carbide-forming elements, when introduced into steel in sufficient quantity, is to combine with the whole of the carbon present, leaving none to be directly associated with the iron. The authors believe that these special carbides are either insoluble in ferrite or incapable of being precipitated as a result of straining and subsequent ageing ; in any case there is no carbide precipitation as a result of straining and ageing and, therefore, no hardening can be produced by this treatment. Further, if no carbon is dissolved in the ferrite, there can be no special distortion of the space-lattice at and near the crystal boundaries. Therefore the material behaves like most other pure metals and non-ferrous alloys, namely, no yield point is observed on a tensile stress-strain diagram.

It is recognised that other elements besides carbon may have the power of imparting strain-age-hardening qualities to mild steel, and the same may be found to be the case for the yield point.

The Incandescent Heat Co. Ltd. are producing a series of booklets, each dealing with a specific industry. The first of these booklets has just been issued ; it deals with furnaces for the railway industry and covers extensively heating and heat treatment for every phase of railway work. Copies are available.

Tinning Copper and Brass by Immersion

The immersion method of tinning copper and brass, involving plating by simple chemical replacement, without the use of electric current is not so familiar as other methods, and in this article an immersion process and a new tin bath are described which can be used at ordinary room temperature.

METALLIC coatings are applied to various metals and alloys to obtain specific properties, such as appearance and resistance to corrosion. Application by hot-dipping, electroplating and spraying are well known to metallurgists and electrochemists, but the immersion method, involving plating by simple chemical replacement without the use of electric current, is less known. On the other hand, immersion processes are extremely valuable for certain applications, and coatings can be applied to intricate shapes and to a variety of sizes that cannot be handled readily by other processes. An immersion process and a new tin bath that can be used to apply coatings to copper and brass, including intricate shapes, at ordinary room temperature, is described by J. D. Sullivan and A. E. Pavlish,* of the Battelle Memorial Institute, and is of interest.

Typical baths that have been used for the deposition of tin by immersion are a saturated solution of cream of tartar containing stannous chloride; a bath containing ammonium alum and anhydrous stannous chloride; and an alkaline bath containing stannous chloride, sodium hydroxide, and sodium cyanide. Immersion coating of copper and brass articles has been practised to a limited extent, particularly on pins, screws, etc., and baths similar to those described have been used. As such baths have to be operated at boiling temperature, and as a contact metal is frequently necessary, no great practical application of immersion coating has resulted.

The new process comprises applying a coating of tin to copper or brass by a simple immersion process at ordinary temperature. The part to be coated is thoroughly cleaned to remove grease and dirt, and preferably pickled, although pickling is not necessary, immersed in a solution consisting essentially of sodium stannite and sodium cyanide, washed and dried. The better the condition of the metal surface before immersion, the better the appearance of the coating. Either hard or soft brass can be coated, and the process is likewise applicable to copper-coated or brass-coated articles.

The process is essentially one of chemical replacement at ordinary temperature without the use of contact metals, the tin in the bath being replaced by copper dissolving from the metal. When the copper becomes completely coated, the action ceases and no additional copper is built up, and this necessarily results in a relatively thin coating, but one which nevertheless is complete and gives a good degree of protection. In this complex cyanide-stannite bath the concentration of free tin is low, so that the coating is uniform and adherent. The appearance is also pleasing. The concentration of tin in the bath, although low, is sufficiently high to render vigorous stirring unnecessary, and complex shapes, such as the inside of coiled tubing, can be coated. This may be done by circulating the solution, but in many cases filling the tube or pipe with solution, letting it stand for the required time, draining and washing is sufficient, this being made possible by virtue of the use of a cold bath. Tank immersion is practicable and expensive containers unnecessary, wood and steel tanks being satisfactory.

The thickness of the coating obtained depends on the time of immersion. In Table I data are given for a bath containing 50·0 grms. of sodium cyanide, 5·0 grms. of stannous chloride, and 5·6 grms. of sodium hydroxide per litre.

TABLE I.

Period of Immersion in in Bath.	Tin Deposited. Thickness : In.	Weight : Grms./sq. dm.
5 mins.	0·000004	0·006
15 ,,	0·000006	0·012
30 ,,	0·000009	0·017
1 hour	0·000014	0·026
2 hours	0·000021	0·040
24 ,,	0·00014[illegible]	0·262

If a tin-coated article is heated slightly above the melting point of tin to 250° C., the tin alloys in part with the copper. The surface obtained may be given an additional immersion treatment so that three distinct layers are obtained of tin, a diffused layer of copper and tin, and copper. These changes are shown by microscopic examination.

Experiments on the concentrations of the baths, which can be used, show that with sodium-cyanide constant at 50 grms. per litre, and the concentration of tin as sodium stannite, varied from 0·5 to 17·0 grms. per litre, good, bright deposits are obtained in all cases. This indicates that the concentration of tin in the bath is not critical, but that it must be in the stannous condition. The concentration, however, should be high enough so that too-frequent replenishment with sodium stannite or stannous chloride is unnecessary. The effectiveness of the coating from baths prepared with sodium stannite held constant at 4·4 grms. per litre and with sodium cyanide varying from 5 to 150 grms. per litre was determined by immersing cleaned copper specimens in the baths for 5, 10, 30 and 60 mins., and testing the coatings produced for appearance and completeness of the tin coating, and by subjectting them to a hydrogen-sulphide corrosion test. The data obtained show that high cyanide concentrations are desirable, and that by employing them the time required to obtain a satisfactory coating is noticeably decreased. For best all-round service the concentration should exceed 25 grms. of sodium cyanide per litre, and 50 grms. per litre is recommended.

As regards the stability of a bath, no particular attention is required to keep it in working order. Periodic titrations have to be made to ensure that the sodium-cyanide and stannous tin concentrations are high enough, as stannous tin is slowly oxidised in stannite-cyanide solutions to the stannic condition, and in this condition it will not coat. Fairly high concentrations of stannic tin can be allowed with no ill effect, provided the bath contains stannous tin. Sodium cyanide, likewise, decomposes to form carbonate and some cyanogen, but the rate of decomposition is no greater than in cyanide electroplating solutions. Copper dissolved from the copper or brass does not cause trouble in normal solutions.

A satisfactory use for the process has been found in the tinning of pipes, tubes and fixtures used in plumbing. Trouble is encountered in such parts with so-called "green water," resulting from dissolution of copper, and such trouble results if the content of copper exceeds about five parts per million, although colour is detected at concentrations as low as two parts per million. Often the trouble disappears when a non-metallic coating, such as one of insoluble calcium salts, forms on the inside of pipes after a few weeks use. A protective coating to retard

*Metals and Alloys, 1940, Vol. 11, No. 5, pp. 131-134.

temporary dissolution of copper until the non-metallic coating is built up is desirable, and attempts have been made to overcome the difficulty by coating the inside of pipes and tubes by hot-tinning, but the method is expensive, and frequently the coating is not satisfactory in quality. Electroplating the inside of tubes and pipes is impracticable because there is no effective way of getting the current into the inside. A simple tinning process carried out at ordinary temperature is therefore of value.

The process has also a wide application, and use can be found for it wherever a relatively thin coating of tin is required, such as in novelty articles, fixtures, etc. It is also suitable for the tinning of sheet iron or steel previously copper-coated, and as the product can be soldered it may be useful in the manufacture of certain types of containers, and there are possibilities of making a relatively cheap templet with satisfactory properties for many purposes.

Electro-Deposition of Alloys

Although alloy deposition is chiefly used for protective and decorative finishing, increasing interest is being shown in its use for engineering purposes. Progress in this field during the last ten years is briefly reviewed, and some important developments are discussed.

THERE has been a steady increase in scientific and industrial interest in the electro-deposition of alloys, especially during the last decade. The most outstanding fact in this field, of recent years, is that not only colour, but composition within narrow limits is maintained in large daily production. Progress in this field during the last ten years is reviewed by Charles L. Faust,* and it is noteworthy that, while alloy deposition is chiefly used for protective and decorative finishing, there is an increasing interest in its use for engineering purposes.

Plating of alloys on a commercial scale will require either colour or composition reproduction, or both. In addition, the plates will have to be sound, well bonded to the base, and meet certain specifications in physical properties, such as smoothness, hardness, ductility, etc. These properties in alloy deposits depend on: The type of plating bath used; temperature; current density; pH; agitation; concentration; "primary ion ratio"†; common ion effect; complex ion formation; addition substances, and metal impurities in the bath. The economic control of these variables depends on: (1) The chemical stability of the bath in order to maintain the necessary "primary ion ratio" throughout a reasonable bath life period, with or without minor chemical additions; (2) replacement of the co-depositing metals in the same ratio in which they plate out (in general, the ratio in which two or more metals co-deposit is not the same as the primary ion ratio); (3) the interdependence of the primary ion concentrations on the mass action effect of secondary ions; (4) practically complete absence of secondary anode or cathode reactions which cause precipitation of one of the primary ions and consequently report the desired ratio in solution; (5) anode purity; and (6) reasonably simple chemical control.

For plating control and reproducibility it is necessary to know how variation in current density, temperature, primary ion ratio in the bath, pH, concentration, etc., affect the composition and physical properties of the deposit. Obviously, the wider the operating range of these variables, the easier it will be to realise alloy deposition on a commercial scale. For commercial work, the factors controlling results on the cathode are not more important than those controlling the anode process. It does not follow that the bath and conditions which give the best cathode results will also give the best anode results.

In general, the following observations can be made as to the effect of the several variables on the composition and appearance of the alloy deposit. One should remember that the electromotive series as we generally think of it refers only to a static condition of reversible equilibrium between a metal and its ions in a state of unit activity. This series is of very little use in predicting alloy deposition results which are obtained under dynamic conditions that bring about a rearrangement of the electromotive series for the individual cases and solutions. This rearrangement is due to complex ion formation, overvoltage, and polarisation effects.

An increase in current density usually decreases the amount of the more noble metal depositing. The relative nobility of two metals co-depositing might be reversed by a sufficient increase in temperature. Increase in temperature or agitation tends to increase the amount of the more noble metal in the plate. The influence of current density, temperature and stirring can be altered by changes in pH. An increase in the amount of one metal in the bath usually increases the amount of that metal co-depositing, but the extent of increase usually does not have a simple linear relationship. The composition range that a given bath can plate out in co-deposition of two or more metals in sound deposits, is dependent on the limiting current density for one or more of the metals. Spongy or powdery plates frequently result because the limiting current density for one metal has been exceeded. Usually the current density range can be increased by adding a suitable addition agent or salt to the bath. One notable instance of this is the use of tartrates, citrates, etc., in cyanide baths.

Recent research has clearly shown that the pH, the nature of addition agents or salts (whether organic or inorganic) and metal impurities in the bath are of great importance in determining the character of the plate. With the exception of brass and nickel-cobalt deposition, these factors have received relatively little attention. They are generally overlooked as the possible cause for brittle, hard plates, colour changes or composition changes that were attributed to other variables.

By suitable voltage control, one can prevent displacement of a noble metal from the solution on anodes of a less noble metal or alloy. This is eliminated or minimised by using a sufficiently high anode current density. Without anode current density-voltage control, it has been found that a noble metal can deposit on an anode of less noble metal, even though the latter is dissolving with 100% current efficiency.

The deposition of alloys during the last ten years has brought out certain general observations. Alloy deposits may be expected to be denser, harder and brighter than plates of the single metals. There are certain composition ranges where alloy deposits have been found more corrosion resistant, more adherent to the basis metal, more readily buffed, more suitable for subsequent plates, and deposited over a wider range of operating conditions than one or both of the individual metals. In several instances current efficiency has been improved and actual deposition of a metal, such as tungsten or nickel and iron from cyanide baths, made possible by co-deposition with a second metal. Electro-deposition has been successful in producing an alloy where other methods of alloying could not be used. Alloy deposition has frequently resulted in better throwing power than single metal deposition.

For decorative finishing of metals, alloy deposition has found wide use in several of the bright metal-plating

* The Electrochemical Society, Ottawa General Meeting, 1940. Advance copy.
† The concentration ratio of the ions of the co-depositing metals.

processes. The brightness that is obtained depends in part on the co-deposition of a second metal. Commercially, these bright metals are not considered alloy plates, but actually they are alloys. The co-deposition is desired and controlled within known limits. A significant fact in connection with the several bright metal processes is that co-deposition of metals is being carried out commercially, with reproduction of colour and composition within narrow limits. Admittedly, the processes require careful control. Such control requires personnel with adequate technical training and introduces an extra cost factor. However, this is partly offset by cost reductions of other items and by the general improvement in the quality of the finished article plated. A large number of these alloy processes, including brass of closely controlled composition, are operated in automatic equipment.

A bright nickel has to be deposited from sulphate baths which contain selenium or tellurium. Nickel-zinc (up to 4% Zn) alloy is deposited on large scale as bright nickel from sulphate baths containing zinc and an aryl sulphonic acid as brighteners. The zinc (or some other metal, such as cadmium) is essential to obtaining uniformly bright plates. A nickel-cobalt (40% Co) alloy has been used as a bright white undercoat for chromium and rhodium plate. Similarly, nickel-cobalt alloy is deposited as " bright nickel," when using a sulphate-chloride bath containing formate, formaldehyde and ammonium salt and boric acid. It has been found to be flexible, and is reasonably easy to operate on a heavy production schedule. The brightness of buffability of nickel plate are claimed to be improved by co-depositing lead from a sulphate bath.

Bright tin alloy deposition is claimed from sodium stannate baths containing sodium acetate and free alkali, with additions of copper, nickel, or silver as the cyanide. In a bright zinc plating process small amounts of tungsten, molybdenum, chromium or uranium co-deposit with the zinc from a cyanide alkali bath. Molybdenum is the preferred addition, depositing up to 1% in the zinc plate. Another bright zinc plating process uses nickel as an addition metal, with sulphite also present in a cyanide-alkali type of bath. Bright cadmium is said to be deposited from cyanide baths containing a small amount of silver or tin.

Although brass deposition is nearing its hundredth anniversary, the process has been extensively studied during the last decade. In most industrial applications brass plating is controlled for colour and not for composition. It is extensively used in the " finishing " of large quantities of steel hardware. Practically all brass plating is done from cyanide baths.

In many applications, the electro-deposition of coatings for the protection of metal against corrosion is closely associated with decorative finishing. There are other instances where appearance is of minor importance. The former is found in the several bright metal plates previously mentioned. Several recent researches have shown that under some conditions alloy deposits give better corrosion resistance than either of the two metals deposited alone. Cadmium-zinc alloys, for instance, have been found more resistant to salt spray tests than cadmium or zinc alone. Mercury-zinc alloy is deposited because zinc does not readily plate on cast iron, whereas the zinc-rich alloy can be deposited. This type of alloy is also one of the bright metal type of plates. Nickel-cobalt alloy plating is claimed to be more corrosion resistant than pure nickel. Various processes are applied in depositing copper-tin or copper-tin-zinc bronzes, while alloys of tin with nickel, copper, silver or cobalt are deposited on cold-rolled steel.

Good corrosion protection is claimed for electro-deposited tin-zinc alloys plated from baths containing zinc cyanide, sodium hydroxide, and sodium chloride to which a solution containing stannous chloride and sodium pyrophosphate is added. Co-deposition of nickel with tin from a stannate bath has been found to greatly harden the tin plate. Lead-bismuth and lead-thallium alloys when deposited have corrosion-resistant properties, the former, containing 75 to 85% lead, being resistant to hydrochloric and sulphuric acids.

Much work has been done with the object of preventing silver plate tarnishing. The problem is generally complicated by the fact that not only must the finish be tarnish-resistant, but it must also have as good or better colour than sterling, or it must retain, essentially, the high light reflectivity of silver ; or it must be more wear-resistant. During the various studies of this problem, silver alloys have been electro-deposited, in which silver is alloyed with cadmium, indium, nickel, cobalt, copper, iron, zinc and lead. The high silver alloys with cadmium and zinc were slightly more tarnish-resistant, whereas those with cobalt, nickel, copper and lead were more readily tarnished than pure silver. The silver-iron alloys proved more resistant to tarnish, yet were not entirely tarnish proof.

Tungsten alloy deposits apparently are resistant to a large number of acids and chemical reagents. These include tungsten-nickel, tungsten-iron, but work has been carried out on the electro-deposition of tungsten alloys with tantalum, nickel, cobalt, chromium, copper, iron, manganese, mercury, silver, tin, etc.

Bearing tests on electro-deposited copper and graphite have shown good performance. The graphite is more evenly distributed than in bearings made by the compressed powder process. Test results have also shown that electro-deposited high-cadmium, low-silver alloys functioned suitably at heavier load and higher temperatures than babbitt. Silver-lead bearings have given good performance under relatively heavy loads. On account of the difficulties in casting and applying these alloys, their electro-deposition offers great promise as a manufacturing process for producing such bearings.

A remarkable amount of information is presented in this detailed discussion by C. L. Faust on the electro-plating of alloys. The necessity for close control of the various processes is emphasised in order to obtain, within narrow limits, the composition of the alloys deposited and to maintain the required composition in large daily production, but the degree of control does not exceed that required in production plating of the several bright metals.

Recovery of Molybdenum from Copper Ores

When an oxidised copper ore is leached with sulphuric acid the resulting copper sulphate solution may contain a small proportion of molybdenum compounds in colloidal form. It has been observed that these colloids carry a negative charge and a process for their rapid separation* involves precipitation with a positively charged colloid (e.g., glue).

The copper sulphate solution for treatment in this manner may contain 20–70 (grms. per litre) copper, 70–5 sulphuric acid, 0·1–10 nitric acid, 0·5–10 iron, 0·3–8 molybdenum, and 0·01–0·3 chlorine, as well as small traces of many other metals. This solution is first agitated with a reducing agent, such as copper cement, the chief function of which is to reduce the iron in solution to the ferrous condition and to precipitate most of the chlorides as cuprous chloride. At the same time, however, it brings the molybdenum in solution into the form of colloidal hydrated molybdenum oxide, $Mo_3O_8 . 5H_2O$. The excess of metallic copper used in this operation is removed before proceeding to the glue treatment. An aqueous glue suspension is employed and is thoroughly agitated with the reduced electrolyte liquor. Precipitated molybdenum oxide then settles out rapidly and the clarified liquor can be drawn off after a short time and transferred to an electrolytic cell for recovery of the copper. The molybdenum oxide is filtered or centrifuged and is convertible into a marketable form without much difficulty.

* U.S.P. 2,188,472, Chile Exploration Company.

The Rolling of Magnesium

EXPERIMENTS have been carried out in order to study the effect of cold work and subsequent annealing on magnesium. The work, which is reported by Professor W. R. D. Jones and L. Powell,* concerned the production of slabs of magnesium, hot-rolling them to 10-gauge sheets and then cold-rolling them with varying degrees of deformation to 16-gauge. The sheets were subsequently annealed at different temperatures and tested. The magnesium used for melting was in the form of 1 in. diameter cast rods, which had the following analysis: Silicon, 0·026; iron, 0·046; and manganese, 0·012%; zinc, copper and lead, nil. The production of the slabs, hot-rolling to 10-gauge, and hot- and cold-rolling from 10 to 16-gauge sheets are described, and particulars and data given of the subsequent mechanical tests to which the sheets were submitted.

Practically without exception, the mechanical properties of the test-pieces cut from sheets in the direction transverse to that of rolling were higher than those in other directions. As a general rule, the values for the properties at 45° to the rolling direction lie between those of the transverse or "strong" and the longitudinal or "weak" directions, approaching the latter rather than the former. The figures for the reduction of area were, in almost all cases, higher than those for the corresponding elongation.

The effect of cold work was to increase the proof stress and ultimate stress to a maximum with 10% cold extension. Further cold-rolling up to 50% extension diminished the values seriously in the weak and 45° directions, but only slightly in the strong direction; above this amount there was little difference. The ductility of the sheets show a serious decrease on cold-rolling to 5% extension, then an appreciable increase on 10% cold extension, followed by a more or less rapid decrease up to 50%; beyond this the ductility was little affected in the weaker directions, and was decidedly improved in the strong direction. The hardness values increased rapidly with cold-rolling to 10% extension, and then remained constant to 50%, after which they again increased rapidly and regularly. The values followed generally the same trend as the ultimate strength in the strong direction.

In the case of the sheets that had been hot-rolled from 10 to 16-gauge, the slight directionality imposed practically disappeared on annealing at 300° C. Those sheets which had been cold-rolled to 5% extension were improved as regards their tenacity and ductility by a low temperature anneal at 100° C. These values were decreased by annealing at higher temperatures. Directionality, which was less pronounced than in the case of sheets which had not been cold-rolled, was not affected by annealing. The hardness values were increased by annealing up to 200° C., which is suggestive of strain-hardening, but annealing at higher temperatures caused a rapid softening of the sheets. Sheets rolled with 10% cold extension showed more pronounced directionality, which was, however, lessened on annealing. The tenacity figures were diminished with increasing annealing temperatures. Although the ductility was not improved by annealing, directionality was lost after annealing at 300° C. The figures became erratic when the sheets were annealed at temperatures higher than 300° C. The hardness decreased more or less uniformly with increased annealing temperature.

In the case of sheets which had been rolled with 25% cold extension, directionality was more pronounced in the figures for ultimate stress and proof stress, but was more or less suppressed in the limit of proportionality. These values were, however, all reduced by annealing, the decrease being less apparent at annealing temperatures higher than 300° C. The ductility figures, which were low in the "as-rolled" condition, were improved after annealing at 300° C., but annealing at higher temperatures was of no advantage. Annealing at 100° C. caused a slight decrease in hardness which continued uniformly on annealing at higher temperatures.

Sheets which had been rolled with 50% cold extension had marked directional properties, and annealing, whilst not affecting seriously the ultimate stress, decreased the limit of proportionality and the proof stress. The ductility was distinctly improved by annealing—the improvement increasing with increasing annealing temperatures up to 400° C. The hardness showed a corresponding uniform decrease with increasing annealing temperature beyond 100° C. Sheets which had been cold-worked more severely showed similar properties; directionality was very pronounced, and was persistent even when the annealing temperature was increased to 500° C. The strength in the strong direction was increasingly greater than in the other directions. Annealing generally caused the tensile properties to decrease; the ductility figures, however, were not improved by annealing at temperatures higher than 300° C. The hardness values decreased uniformly with increasing annealing temperature, and very low values were obtained on annealing at 500° C. sheets which had received 75 and 100% cold extension.

By cross rolling and diagonal rolling 16-gauge sheets were produced from 10-gauge sheets by hot-rolling and by cold-rolling without intermediate annealing. Although it cannot be stated that the results of the tests showed that cross rolling or diagonal rolling produced much better sheets than did straight rolling, the general impression was gained that both methods of rolling were an improvement over straight rolling, and that cross rolling would give a better sheet than diagonal rolling.

The authors discuss the examination of the specimens under the microscope and give grain size data.

Steelworks Plant and Equipment

Many readers will be familiar with the "Wellman" steelworks plant and equipment publication issued by the Wellman Smith Owen Engineering Corporation, Ltd., at intervals, and will desire to have a copy of the new issue just published. We had cause to comment on the excellency of this publication when the last issue was available; in the new issue the high degree of excellence is maintained, but is more comprehensive than any previous issue, comprising as it does 235 pages of information on the products and developments of this enterprising firm.

Since the last issue was published the British iron and steel industry has been completely reorganised, involving the modernisation or entire reconstruction of many steelworks, and also the building of many important steel plants in other parts of the world. In a large number of these schemes, both in Great Britain and overseas, the Wellman Smith Owen Engineering Corporation has contributed in no small degree; designing and supplying special furnace plant and mechanical equipment for the production of steel from the melting shop to the finishing stages.

Representative examples of plant and equipment supplied are illustrated and described in this new publication. The large number of illustrations indicate the general nature of this firm's activities, and show the range of products from the smallest units to the construction of the complete plant. This "Wellman" publication is a credit to the printers as well as to the firm, and anyone genuinely interested in steelworks plant should send their request direct to the London offices of the Wellman Smith Owen Engineering Corporation, Ltd.

Corrosion of Steels by Molten Nitrates

The corrosion of steel containers by molten alkali nitrates is important in the heat-treatment of aluminium alloys in salt baths. The results are given of an investigation on the process, carried out with special reference to the effects of temperature, method of heat application, impurity in the salt, and the influence of the material forming the pot.

FOR the precise temperature control demanded in the heat-treatment of aluminium alloys it is usually found desirable to make use of a fluid heating medium, and the furnaces most frequently installed for the process are baths of molten salt. Suitable salts are sodium nitrate, m.p. 309° C., or the equimolecular sodium-potassium nitrate eutectic melting at 218° C. The advantage of the low-melting-point mixture is that less strain is imposed on the salt container during heating up and cooling down, so that for intermittent work the employment of the eutectic is recommended. When a bath is to be used continuously the melting point of the salt is less important. From the point of view of heat-treatment it is essential that the fused salt shall have no undesirable chemical effect on the metal, and for this reason it is sometimes specified that the salt shall contain no free acid or alkali.

The salts are melted in open welded vessels of mild steel, externally heated, and it is hardly surprising that under these circumstances there is some oxidation of the vessel by the molten salts. In practice it is found that some salt baths withstand this corrosion satisfactorily while others are very rapidly attacked and are ultimately perforated, so that the molten salt escapes and may do much damage. Examination of a number of installations where this had happened has failed to locate the cause of the trouble, and the problem has therefore been investigated on a laboratory scale, the results of which are given in a paper by P. Lloyd and Dr. E. A. C. Chamberlain.[1]

Little work appears to have been published on the oxidation of steel by molten nitrates. The only contemporary work known to the authors is the German investigation of two serious salt-bath explosions which took place in that country.[2] In one case perforation of the bath was ascribed to an intensification of the reaction between iron and molten alkali nitrate brought about by local overheating of the bottom of the bath in the presence of sludge. In the other case the cause of failure was thought to be the occurrence of a thermite reaction between aluminium scrap and loose iron oxide lying at the bottom of the bath, the heat developed being sufficient to melt the steel. Aluminium was found to be inert to the molten nitrates at all temperatures up to its melting point (657° C.), so that severe local overheating must first have taken place.

TABLE I.

EFFECT OF GENERAL OVERHEATING AT 500° C.

Pot No.	Salt.	Cl', %.	SO_4'', %.	Time, Hours.	Gain in Weight, G.	Remarks.
Ingot Iron. Carbon, 0·05%.						
1	Commercial sodium nitrate.	0·40	0·19	350	—	Thin layer of black adherent scale.
3	Commercial eutectic + 1% nitric acid.	0·18	0·09	350	—	Thin layer of black adherent scale.
4	Commercial eutectic + chloride + sulphate.	0·36	0·57	350	4	Unchanged except for a trace of loose scale.
Mild Steel. Carbon, 0·13%.						
5	Commercial sodium nitrate.	0·40	0·19	350	20	Large loose flakes of scale.
6	Commercial eutectic	0·18	0·09	350	13	Large loose flakes of scale.
8	Commercial eutectic + chloride + sulphate.	0·36	0·57	350	26	Large loose flakes of scale.
9	[illegible] eutectic*	Nil	Nil	350	—	Unchanged.

*Analytical reagents.

[1] Iron and Steel Institute. 1940. Autumn General Meeting.
[2] [illegible] *arbeitsblatt*, 1935, vol. 3, pp. 214 and 313.

General experience, however, shows that pot failure is most commonly caused by local corrosion, not necessarily at the bottom of the pot or at an overheated surface, producing a heavy growth of laminated scale and gradually eating into the metal until it is perforated. No cases of the explosive thermite reaction have been within the personal experience of the authors, but although the effect is unusual it is obviously desirable to prevent any foreign matter from accumulating on the bottom of the bath.

The experimental work in the laboratory reproduced as nearly as possible the conditions prevailing in practice; tests were carried out on small welded steel pots, and a furnace was specially designed so that they could be heated as uniformly as possible. The supply of gas was governed, and accurate temperature control could be maintained. Two series of tests were carried out for 1,000 hours, one at 500° C., a normal working temperature, and the other at 600° C.; heating was continuous, and no aluminium was immersed in the salts. The results are given in Tables I and II. An ordinary brand of commercial salt, as used in heat-treatment practice, was chosen for the experiments, with impurities artificially increased where shown. It is particularly interesting to note the behaviour of pot 18, in which a chemically pure sodium-potassium eutectic to which 0·61% of chlorine had been added as NaCl, was used; corrosion was very rapid, and a large circular hole appeared in the pot within 48 hours.

The results given in Tables I and II, give evidence of the varying resistance of different steels to the corrosive attack and suggest that iron sheet of low carbon content is superior to mild steel. Other early tests showed considerable differences between various mild steels. To investigate this point further, a supply of four different sheets was obtained, the analyses being as follows:—

Steel.	Carbon, %.	Sulphur, %.	Phosphorus, %.	Manganese, %.	Silicon, %.
K	0·09	0·05	0·06	0·4	0·04
L	0·13	0·05	0·06	0·37	0·07
M	0·03	0·032	0·008	0·017	Nil
N	0·05	0·04	0·006	0·02	Nil

A preliminary test was made to determine the corrosion of the four steels in air at 500° C. Samples were cut approximately 2 in. square, degreased with benzene, washed with ether and dried *in vacuo* before weighing. After heating in a muffle at 500° C. for 500 hours the samples were cooled *in vacuo* and weighed. To obtain a comparison with the rate of oxidation in pure molten nitrate at the same temperature, similar strip samples were suspended in a large salt pot for 500 hours. The results of the two tests are given below:—

Sheet.	Weight before Heating, G.	Increase in Weight after Heating in Muffle, G.	Increase in Weight, Mg. per Sq. Cm.	Increase in Weight after Heating in Molten Salt, Mg. per Sq. Cm.
K	19 790	0 397	7 35	41·6
L	19 722	0 413	7·45	—
M	15·295	0·408	7·5	15·9
N	20·680	0·436	7·75	15·8

In the muffle test there was little difference in the amount of scaling of the four samples, but it was found that K, L, and M, instead of forming the laminar scale typical of the

salt-bath tests, had a patina of red oxide, velvety in appearance and similar to the oxidised surface on the outside of the salt pots. The sheet N, on the other hand, had the characteristic laminar scale. In the salt-bath tests the scaling rates were appreciably higher and there was also an obvious difference between M, N, and K.

TABLE II.
EFFECT OF GENERAL OVERHEATING AT 600° C.

Pot No.	Salt.	Cl', %.	SO_4'', %.	Time, Hours.	Gain in Weight, G.	Remarks.
Ignot Iron. Carbon, 0·05%.						
11	Commercial sodium nitrate.	0·40	0·19	350	9	Adherent layer of scale.
12	Commercial eutectic ...	0·18	0·09	350	10	Adherent layer of scale and a little loose flaky scale.
13	Commercial eutectic + chloride + sulphate.	0·36	0·57	350	8	As No. 12, but with a considerable amount of loose flaky scale.
14	Commercial eutectic + 1% nitric acid.	0·18	0·09	350	9	As No. 12, but a little more loose scale.
Mild Steel. Carbon, 0·09%.						
15	Commercial eutectic ...	0·18	0·09	350	22	Heavy growth of laminar scale and some loose flakes.
16	Commercial eutectic + 1% nitric acid.	0·18	0·09	350	18	Heavy growth of laminar scale and some loose flakes.
17	Pure eutectic*	Nil	Nil	350	6	Some flakes of adherent scale.
18	Pure eutectic + chloride.*	0·61	Nil	48	44	Perforated after 48 hours.
19	Pure eutectic + sulphate*	Nil	0·68	350	31	Heavy growth of laminar scale.

* The "pure" salts used were in all cases analytical reagents.

Tests with molten sodium nitrate (chlorine, 0·25%) at 500° C. in sample pots as previously described are listed in Table III, and the results may be summarised as follows :—

Sheet K.—Four test pots, marked local attack in every case, leading to perforation in one instance.

Sheet L.—Two test pots, one perforated, the other the most heavily scaled of its batch.

Sheet M.—Five tests, no local attack in any instance.

Sheet N.—Four tests, local attack in each case, but no perforation, and increase in weight less than with K and L.

The superiority of M (Armco iron) is obvious, but whether the difference is due to the low carbon content, to absence of other impurities, or to lack of segregation, is not clear from the evidence at present available. It is worth recording the fact that practical experience of salt baths fully confirms the conclusion as to the resistance of Armco iron to this form of attack.

Tests were carried out on pots which had been protected by metal spraying, but the protection afforded seems to be

TABLE III.
INFLUENCE OF THE COMPOSITION OF THE POT ON THE CORROSION.
Sodium nitrate (Cl', 0·25%) at 500° C.

Pot No.	Metal.	Time to First Sign of Corrosion, Hours.	Total Time of Test, Hours.	Increase in Weight, G.	Remarks.
C 1	K	36	504	4·2	General attack and several large blisters.
C 4	M	—	504	5·0	Clean, no visible corrosion
C 5	L	24	504	12·1	Large loose flakes of scale and general attack.
C 6	M	—	504	2·0	Clean, no visible corrosion
C 7	N	—	504	5·0	Single large blister, other surfaces clean.
C 10	K. Al-sprayed outside	144	264	16·0	Corrosion one side of pot only.
C 13	M. Al-sprayed outside	—	1,570	Nil	No sign of corrosion.
C 14	N. Al-sprayed outside	384	1,570	12·0	General corrosion inside and outside, loose scale.
C 15	L. Al-sprayed outside	24	,570	15·0	Rapid formation of laminated scale, bottom perforated.
C 20	K	48	1,000	17·0	Very heavy laminar scale on three walls.
C 21	K. Al-sprayed outside	120	456	42·0	Heavy corrosion, two sides perforated.
C 23	M. Al-sprayed outside	—	1,000	3·5	Clean.
C 24	M	—	1,000	2·5	Clean.
C 25	N. Al-sprayed outside	—	1,000	4·5	Two large areas of attack, otherwise clean.
C 26	N	96	1,000	3·0	One large area of attack otherwise clean.

In this test pot C 14 was abnormal in showing external as well as internal corrosion

unreliable, and that the use of Armco iron is a preferable solution to the problem.

An important conclusion from the preliminary tests of Tables I and II is that impurities in the salts cause a very marked acceleration of the corrosion. The impurities investigated, chlorides and sulphates, are those which are actually present in most commercial salts, chlorides being the most common. Their effect was further examined by carrying out a series of tests at 500° C. with varying concentrations of alkali chloride. In order to eliminate effects due to differences between steels, the work on salt composition was done with the mild steel sheet K.

Alkali chlorides are common impurities in the commercial salts used for the heat-treatment of light alloys, and it was found that they are responsible for a marked acceleration in the rate of attack on the steel ; 0·1% exercises a considerable influence. It was found that decomposition of nitrate to nitrite does not proceed to completion and that salt mixtures containing much nitrite are oxidised by the atmospheric oxygen. In one series of tests with sodium salts at 500° C. and in air the equilibrium concentration of nitrite was found to be about 4%. It is concluded that with the sodium salt the presence of 5% or more of nitrite should be helpful in suppressing the corrosion, but with the eutectic a greater addition may be necessary on account of the lower intrinsic dissociation temperature.

Forthcoming Meetings

INSTITUTE OF METALS.
Birmingham Section.

Nov. 7. "Gas Producer Plant," by L. Bailly.

Sheffield Section.

,, 8. "The Deep Drawing of Metals," by Professor H. W. Swift, M.A., D.Sc.

MANCHESTER METALLURGICAL SOCIETY.

Oct. 16. "Intergranular Corrosion," by C. H. Desch, D.Sc., Ph.D., F.R.S.

Nov. 13. "Jointing of Metals," by J. H. Paterson, D.Sc.

INSTITUTION OF ENGINEERS AND SHIPBUILDERS OF SCOTLAND.

Oct. 15. General Meeting : Presidential Address by Wilfred Ayre.

Nov. 12. "Automatic Control for Land and Marine Boilers," by J. E. O'Breen.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

Oct. 18. Presidential Address by W. A. Woodeson.

Nov. 1. Andrew Laing Lecture : "Foundation of the Electrical and Mechanical Transmission of Energy," by Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng.

IRON AND STEEL INSTITUTE.

Oct. 15. Joint Meeting with the Lincolnshire Iron and Steel Institute, Scunthorpe. Dr. E. Gregory's paper on "Anti-Piping Compounds and Their Influence on Major Segregation in Steel Ingots" will be presented for discussion.

SHEFFIELD METALLURGICAL ASSOCIATION.

Oct. 15. "Thermal Changes in Iron and Steel," by Dr. Ezer Griffiths, F.R.S.

Nov. 5. "High-speed Steel," by H. W. Pinder, A.Met.

,, 12. Joint Meeting with Iron and Steel Institute and the Sheffield Society of Engineers and Metallurgists.

Meetings at Sheffield Metallurgical Club at 6-30 p.m.

Bronze Age Foundry

AN archæological expedition of the Academy of Sciences of the U.S.S.R. has discovered the remains of primitive settlements on the shores of Lake Onega. During excavations members of the expedition unearthed a primitive human dwelling-place which they believe to belong to the bronze age. They found numerous and varied articles of clay. The most interesting of the finds was a primitive foundry, in which were the remains of a furnace, some slag, bronze slabs, etc.

Electroplated Tin as a Finish for Brass and Copper-Rich Alloys

By E. E. Halls

Developments in an effort to evolve a tin-plating practice that is trouble-free and reasonably fool-proof do not yet seem to have reached the degree of perfection attained in nickel and chromium, but, in discussing the results of some experimental work, the author is of the opinion that tin coatings can successfully be exploited for small components of brass, bronze, and copper.

TIN may be one of the oldest employed of electroplate coatings, but the extent to which it figures among commercial electrodeposition processes is almost insignificant alongside such extensively operated ones as zinc, cadmium, copper, nickel and chromium. The reasons for this at first sight are several, but none of them appears to present fundamental difficulties that could not be surmounted if serviceability of the plated coatings proved them to be equal to or better than established coatings at economic production costs. The popular plate finishes of to-day have all had to pass through slow development stages, both in research and on a manufacturing scale, and the same intensive effort to evolve a tin-plating practice that is trouble-free and reasonably fool-proof does not seem to have yet been made to an extent comparable with that which necessarily preceded the stage of perfection attained by nickel and chromium to-day. This, of course, is in no way ominous for tin in the future, and movement at the moment, including field trials, suggest that its more positive prominence is not so very far distant.

Thin coatings of tin on iron and steel applied by hot dipping methods (" tin-plate ") afford extraordinary good protection against rusting. To this end, they rely largely upon freedom from porosity, but the tin coatings themselves retain their lustre throughout long service. To a lesser degree, tinned brass and copper, similarly produced, exemplify the qualities of tin for yielding good protection when present in very thin films. The separation of copper conductors from their rubber coverings by means of tin is a typical case in point. The focusing of attention upon the merits of tin-plating for miscellaneous articles of copper, bronze, brass and other copper-rich alloys is a natural development, therefore. Tin is a metal of naturally attractive appearance, capable of taking a good polish, in which condition it is not easily wetted, dirtied or finger-marked. When deposited electrolytically, tin is prone to be very much more porous than when coated by hot dip methods. It is practicable, however, to offset this defect, as with other electroplate coatings, by building up rather thicker films. Moreover, when polished coatings are concerned, porosity is to a considerable extent mitigated by the flowing over of the superficial metal.

The most popular electroplate finish for brass and similar non-ferrous components is nickel, and while extensive quantities of polished work are produced, probably larger amounts of miscellaneous articles are given a nickel-plate finish more or less in the condition they leave the machines from previous fabricating operations. It is the substitution of nickel by tin in such instances with which this article is concerned. In relation to copper, tin is similarly placed in the electrochemical series to nickel, namely, it is electropositive to copper and can protect sacrificially. In behaving in this way, it possesses the advantage of generally forming whitish corrosion products, whereas the nickel compounds are generally green and more noticeable and unsightly. On the other hand, it is not so electropositive as zinc, and therefore in contact with copper or brass will not corrode away so rapidly as does zinc. At the same time, with the present states of development of tin and nickel plating respectively, nickel possesses advantages in that it is easier to produce a uniform plating in repetition work, with constant degree of lustre, colour and hardness. The softness of tin coatings is sometimes a drawback, and uniformity from batch to batch, or even through the same load, with respect to lustre and colour cannot be assured without exercising very rigid control.

The complex chemical constitution of tin plating solutions, their retention at approximately constant composition during working over extended periods, the critical range of efficient current density and voltage values, as well as type of anodes to be employed, are rather formidable features to conservative platers. However, research of recent years indicates that sodium stannate solutions operated hot with inert anodes and at closely controlled current values are reliable, and are capable of development into continuous types of plating plant. In the following, tin coatings of various thicknesses, deposited from two types of bath, alkaline and acid, upon brass articles, are critically discussed from the viewpoints of appearance and behaviour under accelerated corrosion test conditions. For interest, some nickel-plated articles are included in the tests, and also the serviceability of nickel/chromium finishes briefly referred to for comparison. The plating baths and conditions are likewise examined in some detail with respect to efficiency and quality of deposit procurable.

The brass articles employed for the tests comprised miscellaneous small details having bends, holes, reflex surfaces, etc., being typical of the complex type of work passing through the plating department of a light engineering factory. A range of deposit thickness was explored, the thinnest being that sufficient to definitely obscure the brass-base metal. They were prepared for plating by mass methods regularly employed. Thus heavy oil contamination was removed in a trichlorethylene vapour degreaser, and final traces of grease or other contamination by means of a gently boiling solution of mild alkaline degreaser (4 ozs. per gallon of water of a mixture of equal proportions of trisodium phosphate, sodium carbonate, and sodium silicate). Then an acid dip, constituting a few seconds immersion, in a mixture of 3 volumes nitric acid, 1 volume sulphuric acid (cold), followed by cold and hot water rinses, a hot 5% sodium cyanide rinse, cold water wash, was applied as a final treatment immediately prior to entering the plating vats.

Table No. 1 gives data concerning the average thicknesses of tin coating on the various batches of articles tested, the letter and numerical designation given therein to the various lots of specimens being retained throughout the other tables. It will be noted that the thickness of the tin deposits range from approximately 0·00005 in. to approximately 0·0005 in.

Table No. 2 describes the appearance of the coatings after a lengthy period which was judged sufficient for any discolouration by ageing to have asserted itself. On the whole, the A series from the alkaline bath show superiority over the B series from the acid bath. Both, however, could be lightly scratch-brushed or buffed to pleasing polish, or could be lacquered to withstand wear and tear of handling and assembly without bruise-marks becoming apparent.

Table No. 3 summarises the results of exposure to a relatively mild test, comprising a series of daily hot and cold humidity cycles. To secure this, the samples were arranged in a closed cabinet, fitted with controllable heaters and a circulating fan, and provided with a tray of water in the base. Day temperature was maintained at 50/55° C., and night temperature at 18/22° C. The

TABLE I.

AVERAGE THICKNESSES OF ELECTROPLATE DEPOSITS ON COMPONENTS EMPLOYED FOR DURABILITY TESTS.
(See Tables II, III, IV, V, and VI)

AVERAGE THICKNESS OF PLATING EXPRESSED IN TERMS OF MILLIGRAMS/SQ. DCM.

Batch No.	TYPE A. Tin from Alkaline Bath	TYPE B. Tin from Acid Bath	TYPE C. Nickel
1	112	119	176
2	256	368	—
3	496	608	—
4	704	753	—
5	880	1088	2208

NOTE.—Base material for C 5 was phoshpor bronze, all other materials brass.

exposed alongside over the same period. Except for the thin coatings, A1 and A2, performance was good, their being little to choose between the remaining samples, and little really serious deterioration. The nickelled samples proved much inferior.

Table No. 6 appertains to a specialised test, the samples being suspended in a glass chamber containing a tray of water saturated with sulphur dioxide gas. These conditions were imposed to secure some insight into the influence of industrial atmospheres containing sulphurous gases, and of the effect of soot and dirt deposition, as this is generally acidic, due to traces of sulphurous or sulphuric acid. The tin coatings are still superior to the nickel ones, and while the thinner ones deteriorate rapidly under the very rigorous conditions, the results obtained suggest appreciable protection is to be expected from the thicker tin platings.

TABLE II.

"INITIAL" APPEARANCE OF THE TIN PLATINGS EMPLOYED FOR EXPOSURE TESTS IN TABLES III, IV, V, AND VI
(Examined 6 Months after Electroplating).

Batch No.	TYPE A. Tin from Alkaline Bath	TYPE B. Tin from Acid Bath.
1	The tin coating was slightly darkish, with numerous tiny darker pin-point spots. It was slightly lustrous, due to the reflection from the bright base material, but rather easily marked on handling.	The tin coating had a uniform dirty grey matt appearance. It was not easily marked by handling, but readily by burnishing.
2	Tin coating was uniformly clean and greyish white. It was lustrous and easily bruised or burnished, but not readily damaged by handling.	The tin finish was matt white, easily finger-marked or burnished.
3	This was a very attractive white lustrous coating, not easily marked by handling, but soft and readily burnished.	Similar to B 2.
4	Just a little more matt than A 3, otherwise similar and equally attractive.	Similar to B 2.
5	Similar to A 4.	Similar to B 2.

TABLE III.

EXPOSURE TEST RESULTS, VARIOUS TIN- AND NICKEL-PLATED ARTICLES SUBMITTED TO HOT AND COLD HUMIDITY CYCLES FOR A PERIOD OF 30 DAYS.

Batch No.	TYPE A. Tin from Alkaline Bath.	TYPE B. Tin from Acid Bath	TYPE C. Nickel
1	Gradual development of dark brownish mottle, especially from edges, due to tarnishing of base brass. Condition rather poor.	More grey in colour, very little mottling, a little darker than specimens B 2, but markedly superior to A 1.	General dirty blackish tarnish, condition very poor.
2	Markedly superior to A 1, but a slight dark brownish mottle developing. Condition good.	A little more grey in colour, no mottling or staining. Condition very good.	—
3	Practically unaffected.	Very slightly more grey in colour, otherwise unchanged.	—
4	Unaffected.	Unaffected.	—
5	Unaffected.	Unaffected.	General greyish black tarnish with numerous fine points of attack on base brass. Condition poor.

NOTE.—Base material for C 5 was phosphor bronze, all other materials brass.

former secured a humidity of 60/70%, and the latter 100%, with moisture condensation upon the work. The specimens having the thinnest coatings (A1 and B1) fared rather poorly, while A2 and B2, still with rather thin films of tin, behave quite well, and A3, 4 and 5, B3, 4 and 5 exceedingly well. The nickelled specimens C1 and C5 were not so good.

Table No. 4 deals with rigorous salt spray conditions. Exposure was to the mist from 20% salt solution atomised by means of low pressure air. A day's test comprised 8 to 9 hours in the cabinet with spray operating and 15 hours with it off. Specimens were then removed, washed in flowing water and dried with a soft cloth for examination. The tabulated results are self explanatory and few criticisms are needed. It is to be noted that not only are the thicker coatings superior to the thinner ones from the viewpoint of protecting the base material, but also in so far as the tin itself is less corroded. This is evidently a function of the better seal they afford and therefore the diminished influence of the bimetallic junction. Again, the B series from the acid bath seemed to be a little superior to the A series from the alkaline bath, although to some extent this may be ascribed to slight differences in thickness of coating. The nickel coatings showed very appreciably less resistance to the conditions.

Table No. 5 refers to moderately severe exposure, namely, in open weather conditions, the specimens all being

Table No. 7 is merely included for interest, to show how a flash chromium plate over a nickel plating markedly improves the protective qualities of the latter, but that the nickel must be a heavy deposit for this improvement to be of practical significance.

The alkaline tin bath was made up of the following ingredients :—

Sodium stannate	30 ozs.
Stannous chloride (Tin Protochloride) ..	5/8 ozs.
Resin (French, grade F)	0·05 ozs.
Water	1 gallon.

It was operated at 70° C., using nickel anodes, and a current density of approximately 18 amps/sq. ft. of work surface. A range of preliminary trials had shown these to be the best conditions. Table No. 8 summarises the results of these trials. From these data it is seen that with tin anodes, the tendency to form a loosely adherent coarse deposit at edges or prominences could not be eliminated, except by operating the solution cold, when it was hopelessly inefficient at the cathode. Also, it is seen there is apparently a tendency in the electrolyte used for stannous tin to build up and cause a high cathode efficiency. Using lead anodes, somewhat better results were obtained, but with still a marked tendency to form a loose deposit at edges. Nickel anodes provided the best results, deposits being reguline, fine, and generally lustrous. The lowest of the amperages tried offered best efficiency.

TABLE IV.

Exposure Test Results, Various Tin- and Nickel-plated Articles Submitted to Salt Spray Test for 180 Days.

Batch No.	Type A. Tin from Alkaline Bath.	Type B. Tin from Acid Bath.	Type C. Nickel.
1	Slight to heavy attack in 2 days. Base metal bared in places, becoming dark and mottled. Condition bad, and test discontinued after 2 days.	Tin slightly attacked on first day, gradually developing to heavy corrosion in 7 days. Base brass not badly affected. Condition poor, but much superior to A 1. Test discontinued after 7 days.	Brass heavily attacked, greenish corrosion products very evident in 7 days. Gradually extending till in 56 days attack was heavy over all surfaces, green corrosion products very brilliant and thick.
2	Light attack on tin evident in 14 days, becoming slight to heavy in 56 days. In 180 days, attack was further advanced, and a black speckle or mottle developed where the tin was completely penetrated.	Tin coating showed slight attack in 7 days, with little further change in 14 days. In 56 days, the underlying brass was attacked from slightly to fairly badly on various samples. In 180 days, attack ranged from fairly bad to bad. A darkish grey speckle and mottle developed. These samples were a little inferior to A 2.	—
3	In 14 days, a general slight attack on the tin was evident. Brass was still unattacked in 56 days, but showed marked attack in 70 days. Not much further deterioration was apparent, in 180 days, and the dark grey speckle and mottle was not so apparent as in A 2.	In 7 days, slight attack was evident on the tin coating. The base brass showed some attack in 56 days, varying from slight to moderately bad. In 180 days, little further deterioration was revealed, the general appearance was a light brownish grey mottle, a little superior to A 4.	—
4	14 days revealed little effect, and 56 days only a slight attack on the tin coating. Much superior to A 3. 70 days showed little further change, and 180 days fairly bad attack on the base brass, exhibited by blackish spots. These specimens were much superior to A 3.	Slight whitish corrosion of tin in 14 days, little further increase in 56 days. In 180 days, no marked attack on brass was apparent, and the general appearance was a slight brownish colour. Slightly superior to A 4 and B 3.	—
5	The first signs of slight attack on the tin covering were evident in 14 days, with very little further development in 56 or 70 days. At the end of 180 days, the brownish speckle or mottle was noticeable, but condition better than the A 4 specimens.	Specimens unaffected in 14 days; tin slightly attacked, but brass unaffected in 56 days. 70 days revealed no further change. 180 days revealed no appreciable attack on the brass. The general appearance was a brownish grey with whitish patches, greatly superior to specimens A 5.	Greening and slight attack on bronze evident in 7 days. 21 days revealed an increased attack, and 56 days showed the surfaces entirely covered with small spots of green corrosion product, which was thick and heavy. Condition very poor, and test discontinued.

TABLE V.

Exposure Test Results, Various Tin- and Nickel-plated Articles Submitted to Outside Atmospheric Test for 180 Days.

Batch No.	Type A. Tin from Alkaline Bath.	Type B. Tin from Acid Bath.	Type C. Nickel.
1	Appearance in 7 days was blackish, and at end of period it was a blackish brown mottle, giving an extremely dirty effect. Condition very poor.	In 14 days, tin coating was badly attacked, giving whitish deposit, and some blackening of base brass. In 100 days tin was completely corroded. Little further change in 180 days. Condition very poor.	No apparent attack in 14 days Dirty black tarnish and greening in 100 days Little further change in 180 days. Condition very poor.
2	Slight attack on tin evident from white corrosion deposit in 14 days. Dirty grey mottle on account of more intense attack on tin in 180 days. No attack on base brass evident. Condition good, superior to A 1.	Tin very slightly attacked in 14 days, becoming a dirty grey mottled appearance in 180 days. Condition good, much superior to B 1, and about equal to A 2.	—
3	Very similar to A 2.	Very similar to B 2.	—
4	Ditto	Ditto	—
5	Ditto	Ditto	General dark tarnish, becoming green, due to attack on nickel in 14 days. Very poor in 180 days.

TABLE VI.

Exposure Test Results, Various Tin- and Nickel-plated Articles Submitted to an Atmosphere of Moist Sulphur Dioxide.

Batch No.	Type A. Tin from Alkaline Bath.	Type B. Tin from Acid Bath.	Type C. Nickel.
1	—	—	Specimens were slightly darkened in 60 minutes and entirely black with brass bared in 120 minutes.
2	Slight darkening occurred in 15 minutes and heavy white corrosion products in 150 minutes.	Slight darkening was produced in 15 minutes and heavy attack along edges in 60 minutes. Samples were black all over, with white corrosion products at edges in 120 minutes.	—
3	Darkening and slight corrosion appeared in 60 minutes and heavy white corrosion products along edges in 150 minutes. Superior to A 2.	Slight darkening was revealed in 30 minutes and heavy white corrosion along edges in 120 minutes. A little inferior to A 3.	—
4	—	—	The samples blackened appreciably in 3 minutes, and completely in 15 minutes. In 60 minutes condition was exceedingly poor, and surfaces were sticky.

TABLE VII.
TEST RESULTS ON CHROMIUM-PLATED BRASS AND COPPER COMPONENTS.

Batch No.	Base Metal	Average Thickness of Electro-plate Coatings, Mgms./Sq. Dcm.		Exposure to Salt Spray Test.
		Nickel	Chromium.	
6	Brass	472	33	Condition very poor in three days, when coating blistered and flaked very badly.
7	Copper	1600	20	Green corrosion compounds appeared on all edges in 30 days. Little further develope in 180 days. No tendency to blister or flake.

TABLE VIII
ALKALINE TIN SOLUTION A. QUALITY OF DEPOSIT AND CATHODE EFFICIENCY WITH DIFFERENT ANODES AND TEMPERATURES.

Types of Anodes	Temperature °C.	Cathode Current Density Amps./Sq. Ft.	Amount of Tin Deposited, Mgms. per Sq. In.			Cathode Efficiency, %	Quality of Deposit
			Time, Minutes.	Actual.	Theoretical.		
Tin	70	15	15	27·2	28·9	94	Loose crystalline deposit at edges, rough, grey, somewhat pitted.
,,	70	10	20	27·0	25·7	105	Loose crystalline deposit at edges, rough grey, somewhat pitted.
,,	70	10	10	15·0	12·8	117	Loose crystalline deposit at edges, tending to be smoother.
,,	70	6	20	13·4	15·4	86	Loose crystalline deposit at edges, tending to be smoother.
,,	20	10	30	2·0	38·5	5·2	Smooth, but inefficiently thin.
Lead	80	5	23	13·5	14·7	92	Loose crystalline deposit at edges. Grey, a little rough.
,,	80	10	10	11·5	12·8	90	Loose crystalline deposit at edges, whitish, smooth.
,,	80	15	16	29·0	30·8	94	Loose crystalline deposit at edges, dark grey, smooth.
Nickel	70	15	30	51·0	57·8	86	No loose deposit at edges, smooth, lustrous.
,,	70	30	15	32·0	57·8	55	No loose deposit at edges, smooth.
,,	80	50	6	16·0	38·5	42	No loose deposit at edges, smooth.

TABLE IX.
ACID TIN SOLUTION B. QUALITY OF DEPOSIT AND CATHODE EFFICIENCY WITH DIFFERENT CURRENT DENSITIES.

Type of Anode.	Temperature °C.	Cathode Current Density, Amps/Sq. Ft.	Amount of Tin Deposited Mgms. per Sq. In.			Cathode Efficiency, %	Quality of Deposit.
			Time, Minutes	Actual.	Theoretical		
Tin	20	9	10	10·0	11·6	86	Greyish white, reasonably smooth.
,,	20	9	30	23·0	35·4	65	Greyish white, reasonably smooth.
,,	20	18	10	13·0	23·2	56	Greyish white, smooth, seemed to throw better than at 9 amperes.

The acid bath referred to as "Type A tin" was of rather special make-up, very similar to the sulphate tin solutions containing cresols operated on the Continent. It was prepared in the following manner: One pound of sulphocresylic acid was dissolved in a gallon of water and charged with tin electrolytically. The tin anodes were contained in canvas bags, and iron cathodes were used. The current employed was 40 to 60 amperes per sq. ft. of anode at 2 to 2½ volts. The solution was then filtered and employed in an enamelled iron tank.

Cast or rolled tin anodes can be used, and for the experiments, the solution was operated cold, at 18 amperes per sq. ft. of cathode surface, which seemed to be the best conditions. The effective anode surface should approximate to that of the cathode surface, because excessive anode efficiency causes a tendency to rough deposits, while deficiency of anode surface promotes over exhaustion of the solution. A summary of cathode efficiencies at various current densities are shown in Table 9.

From the above, it can be seen that tin possesses great possibilities as an electroplate finish, and considerable attention is being directed to it for small components of brass, bronze and copper, on account of the premature failure of nickel coatings in certain instances. It is considered that the successful exploitation of tin coatings hinges largely upon the appreciation at the outset of two features fundamental to the technique of all electroplate processes, namely, firstly, the specification of an adequate thickness of coating, and secondly, efficient process control. The above limited investigation indicates that, for non-ferrous components, minimum average deposit thicknesses should be 400 milligrams of tin per square decimetre (approximately 0·00025 in.) for mild service conditions, and 800 milligrams (approximately 0·0005 in.) for more severe exposure. Also, it points to the alkaline stannate bath operated hot and with nickel anodes as the most successful type of process, but this necessarily demands regular analytical control to maintain a constant tin content and cathode efficiency. The sulphocresylic acid type of electrolyte has marked advantages over any other baths operated with soluble anodes of tin and claims investigation further. The development of a practical technique in production, using rotating cathode plants, should not prove a very difficult proposition, and the ultimate outcome will be watched with interest.

Materials for Vacuum Tube Manufacture

The requirements of metals and alloys for cathodes, anodes, and grids are discussed by A. J. Monack, and a brief treatment of thermionic emission in the case of oxide-coated, thoriated-tungsten, and tungsten filaments is given. Some of the salient features are given in this article.*

THE passage of electric currents between the electrodes of vacuum tubes produces effects which make these tubes useful in various ways; and the cathode is the heart of the tube, since electron emission from this electrode forms the current which determines the characteristics of the tube. The cathode must satisfy three requirements: The required rate of electron emission must be available; the cathode must have a satisfactory life; and the structural strength at high temperatures must be sufficient for the cathode to retain its shape. Since the first two requirements are in opposition, careful choice of materials and design is necessary.

Metals for cathodes must emit electrons easily (low work functions); must have low vapour pressures so that evaporation does not cause early failure; must have high melting points, low thermal conductivities to prevent rapid heat conduction away from the cathode, high tensile strength, and stiffness; and must not fail by creep. Some compensation for failure to meet these requirements completely is possible by changes of cathode shape—e.g., the use of ribbon cathodes.

A heated tungsten filament was one of the early commercial sources of electrons, and tungsten is still the filament material in nearly all large power tubes. The wire must be pure and uniform in properties and dimensions. A local reduction in diameter, for instance, would cause overheating and subsequent burn-out at that point. The electron emission efficiency (emission current per watt of heating power) increases as the temperature increases, but the evaporation rate of tungsten sets an upper limit. In order to obtain greater emission efficiency without exceeding the safe operating temperature of the filament, tungsten wire to which has been added 1 to 2% of thoria is often used. The emission efficiency at the operating temperature is increased about tenfold by this method. These filaments may be heated in an atmosphere of hydrocarbons, such as acetylene, benzene, etc., in order to form a surface layer of tungsten carbide. Activation, by heating briefly at 2,300–2,500° C., results in the production of some thorium by reaction between thorium oxide and tungsten; and subsequent "ageing" at 1,750–2,000° C. permits the thorium to diffuse to the cathode surface, the active surface layer apparently being about one atom thick. Under operating conditions (1,500°–1,700° C.) a small amount of metallic thorium is always diffusing towards the surface. The layer of tungsten carbide, having larger grain size than the tungsten, prevents too rapid diffusion and reduces thorium evaporation from the surface. Thoriated tungsten filaments need not be carbonised, and are sometimes used without that treatment.

The use of very high potentials, as in power tubes, results in bombardment of the filament by gaseous ions. These ions remove thorium from the cathode surface at a relatively rapid rate, and for this reason pure tungsten filaments are generally used in high-power tubes, despite the higher cathode temperature required and the poorer efficiency obtained.

In many cases it is necessary to obtain good emission at relatively low temperatures, as in the case of receiving-type radio tubes and similar types. Unfortunately, the best emitters have melting points which are too low for use even in such tubes. Cesium is an excellent emitter, as are barium and strontium; but the melting points are too low. However, it has been found that if such metals are applied to the surface of other metals, the evaporation is not so great as when the second metal is not present. Cesium may be deposited upon silver or tungsten, and barium upon nickel, platinum, or their alloys. A mixture of barium and strontium carbonates is usually applied to a wire of nickel or nickel alloyed with silicon, cobalt, iron, or titanium, or to a wire of platinum alloys containing nickel, cobalt, rhodium, or iridium. At the operating temperature (700°–900° C.) some metallic barium and strontium are produced, and these metals, in a layer probably about one atom thick, act as the emitter. A small amount of the active metals is produced continuously from the oxides by electrolysis resulting from the flow of electron current.

With tubes having cathodes heated by alternating current, it is usually necessary to separate the cathode circuit from the heating circuit, which is done by inserting a heater wire into a tubular cathode, usually of nickel, coated with barium and strontium carbonates. An insulator of alumina, beryllia, or magnesia separates the heater from the cathode. In this arrangement the cathode temperature is, as before, 700°–900° C., but in order to attain this temperature, the heater must reach 1,000°–1,400° C. Tungsten is one of the most-used heater materials.

Requirements for the purity of cathode metal, ceramic insulation, heater wire, and the carbonates are specially strict. A cathode is readily "poisoned" by numerous impurities. The resultant poor emission does not become apparent until the tube is practically completed. Oil and grease must be removed from all parts used in a tube, gases must be removed as completely as possible, and the tube parts must not be permitted to stand for any great length of time exposed to the atmosphere. In addition to maintaining the purity requirements, it is essential that the physical and chemical characteristics of the carbonates be controlled with extreme care.

The anode (plate) is the second most important electrode in a vacuum tube, since the electrons emitted from the cathode must be collected by the anode in order to furnish output current. To keep the dimensions of the tube as small as possible, the thermal loading of the anode must be as high as possible. This stipulation places definite restrictions on the materials which can be used. The heat generated by electronic impact can, in small tubes of conventional design, be dissipated only by radiation, since conduction is negligible. In the case of water-cooled tubes or others in which the anode forms part of the external envelope, conduction is utilised for cooling the anode, and radiation is negligible.

With tubes of low power output, the anode is made of nickel, iron-strip, or nickel-plated iron. When greater heat dissipation is necessary, the nickel strip is carbonised to give it a coating of amorphous and graphitic carbon. Where plate voltages and operating temperatures are high, the liberation of gas from these anodes would be serious, and in such cases molybdenum and tantalum are used. The radiation may be increased by blasting with silicon carbide or by coating with finely powdered metal, such as tungsten. Anodes of graphite are used extensively, but they generally require special treatment to decrease the large gas content.

When the heat generated becomes too great to be dissipated by radiation alone, water-cooled anodes are necessary. Such anodes are part of the envelope, and must not only be ductile enough to be drawn into shape, but must give a vacuum-tight seal to glass. Copper and Fernico meet both requirements.

In a three-electrode tube (triode) the grid is useful

* *Ind. Eng. Chem.*, vol. 32, No. 8, 1940, pp. 1,028-33.

because small changes in grid voltage cause relatively large variations in plate current. This action is the basis of the amplification process in a vacuum tube. Additional grids are used to modify the electrical characteristics of a tube. The shape and position of the grid relative to the other electrodes in the tube is extremely important. Consequently there are definite requirements to be met.

Material for grids should, wherever possible, have a relatively low thermal expansion in order that serious buckling at elevated temperatures may be avoided. The drop in elastic limit at 1,000° C. should be small enough, so that the grid is not permanently deformed by the magnetic or thermal forces set up by high-frequency inductive heating during exhaust. The cold ductility must be sufficient for proper forming of the grids. The grid material must be one with a high " work function " ; that is, it should be a poor emitter of primary and secondary electrons. This requirement may be made less severe by plating or coating the grid with metals or other substances that decrease electron emission.

Molybdenum has most of the necessary properties, but is rather expensive. When cost is a consideration, it is often practicable, by changes in design and construction, to use other metals, such as alloys of chromium, iron, or manganese with nickel, or nickel alone.

The problem of making electrical connection between the internal elements of a vacuum tube and the external wires and studs is often extremely troublesome because of the difference in thermal expansion between glass and metal. In the early days platinum was widely used as the sealing metal ; but this process was costly, and one not entirely free of difficulties.

In present practice with soft glass the most common sealing metal is a composite lead called " Dumet." In manufacturing this material, a core of nickel-iron is sheathed with copper, and the two are brazed together and then drawn through a die to the desired diameter. The thermal expansion of such a combination does not exactly match that of lead glass, but the copper sheath flows sufficiently under stress to prevent cracking of the glass. Another type of alloy is finding increasing use with soft glass—namely, chromium-iron alloy which contains 26–30% chromium. Proper design is important, since soft glasses do not match the thermal expansion as closely as could be desired.

For hard glasses the sealing materials are tungsten, molybdenum, and an iron-nickel-cobalt alloy called " Kovar " or " Fernico," which consists of approximately 54% iron, 28% nickel, and 18% cobalt. Special borosilicate glasses are used with these metals, and while the thermal expansions in no case match exactly, good seals can be made. The expansion curve of Fernico is unusual in that it has an inflection point which coincides roughly with the inflection point of the glass used.

Producer Gas Cleaning

The Whessoe Foundry and Engineering Co., Ltd., of Darlington, during the past ten years, has developed two systems of producer-gas cleaning, by means of which any degree of cleanliness may be obtained in the gas produced. It is well known that raw producer gas causes many difficulties in the proper control, distribution and use of this fuel, and it cannot be used for the firing of furnaces fitted with small orifice burners and require accurate temperature control. As a result of the developments of this company, however, clean producer gas can now be supplied for firing purposes where the most stringent conditions regarding freedom from impurity are imposed, and, moreover, the overall cost per therm of the clean gas is an exceedingly attractive figure, comparing favourably with the charges of alternative methods. These cleaning systems are discussed in an informative brochure recently published by the company, copies of which may be obtained on application.

Development of Antimony Deposits in Iran

Certain parts of the great desert region in Central Iran have been known for a long time to be rich in metal ores. This is particularly the case in the district round Anarek, where a German expedition recently prospected the veins of antimony glance located at a height of over 5,000 ft. near Patiar and Turkemani.* The nests of antimony glance were found to range in width from 8 in. to 5 ft., and average samples analysed to 60–65% Sb. In one of the mountain ridges a main vein about 1,600 ft. in length could be traced. The extent of the deposits, representing some thousands of tons of pure antimony, was considered to justify large scale trials with a view to installation of a smelting plant with an annual output capacity of 500 tons. This would leave an ample margin for export after satisfying the current Iranian annual requirements of 200 tons. The ore could be separated from the quartz gangue by hand sorting to a large extent. A typical gangue-free sample contained 71·8% Sb, traces of As and Pb, no Cu, Fe or precious metals. The material was thus highly adaptable to treatment by the non-volatilising roast reduction process, which was actually the only process entering into practical consideration after taking all the local conditions into account. Large scale tests on these lines were carried out in the vicinity at Talmessi, where an experimental smelting plant had been installed for dealing with the local arsenic-containing nickel ores. Oxidation was found to proceed at a satisfactory speed after the ore had been reduced to particles of 2–4 mm. diameter. The size-reduction was accomplished without difficulty by manual crushing with hammers. Starting from a roasting charge containing less than 0·5% sulphur, an antimony of at least 99·8% purity was produced in these trials. It was concluded that the results obtained would justify the installation of smelting plant at the site of the deposits and that the difficulties arising out of the climatic conditions were by no means insuperable.

Electrolyte Films in Acid Copper-Plating Baths

A method of sampling the film of electrolyte immediately adjacent to a plating electrode has been developed. A small hole was drilled through the electrode, and electrolyte slowly syphoned through this hole while the plating operation was in progress. Experimental results for the acid copper-sulphate plating bath are given by Read and Graham.† The copper decrease and acid decrease in the cathode film were studied under various conditions of current density, copper concentration and temperature. Variations in acid concentration were found to affect the film more than changes in copper concentration. An increase in temperature markedly decreases the difference between the film and main body concentrations. The composition of the film was found to be relatively constant as the electrode surface is explored in a horizontal direction ; the difference between the main body composition and the film composition, however, increases as the sample is taken at greater distances from the bottom of the plate, but at a decreasing rate.

Based upon constant film values obtained with a wide variation of copper concentration, it may be concluded that the film samples were close to the equilibrium composition, but some of the variations in film values resulting from rather wide variations in total acid concentration might lead to the conclusion that the film sample does not represent the true equilibrium film conditions, and it is suggested that further experimental data are needed before there can be certainty that the true equilibrium film sample can be obtained by this method.

* Details of the prospecting work appear in March and April issues of *Metall und Erz*, 1940.

† Electrochemical Society paper presented at Ottawa, October, 1940, 23 pp. (Advance Copy.)

Recent Developments in Materials, Tools and Equipment

Improved High-Pressure Die-Casting Machines

TWO new and greatly improved high-pressure hydraulic die-casting machines have been developed and constructed by the G. and M. Manufacturing Company of Cleveland, U.S.A. One is designed for zinc-, tin- and lead- base alloys, and the other for aluminium, brass, and magnesium alloys. Similar in engineering and construction, the machines are designed to accommodate larger dies, to increase production and reduce waste, to give a tighter seal on dies and largely eliminate flash, and generally to facilitate the die-casting process.

Highly important to the performance of the machines is their unusual construction. Base, framework, die-plates and toggle-links are made of steel plates, flame-cut and welded. Welding has been substituted for bolting and riveting wherever possible. The result is a type of die-casting machine which is claimed to be heavier and stronger than any previously manufactured, and better able to stand the terrific wear and tear of high-speed production.

Construction of the extra heavy die-plates is such that any possibility of breakage is eliminated. Welding at the juncture of toggle-link and die-plate further increases strength and durability. All of these factors combine to cut maintenance costs to an absolute minimum.

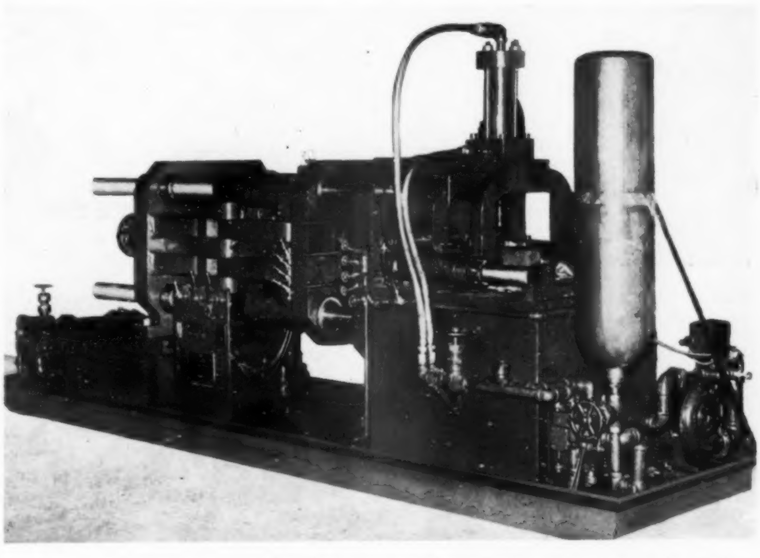
The toggle arrangement permits moving and locking of the die-plates with a hydraulic pressure of less than 300 lb. against the actuating mechanism. Construction and design of the toggle mechanism, however, provides a locking pressure of approximately 500,000 lb.

One feature of the toggle linkage is that no strain is exerted on the link-pins in stopping the forward motion of the movable die-plate, as would be the case if shoes or stops were used on the links themselves. Instead, the machines are so equipped that the actuating movement of the linkage is stopped when the hydraulic piston which moves it comes in contact with the movable die-plate when the die is locked. Steel-hardened bushings are used on all bearing surfaces in the toggle linkage, and the link-pins themselves have an exceptionally large diameter.

Tie-bars also are unusually heavy, and the bearing surface for each tie-bar totals 230 sq. in., distributed over 22 linear inches. This prevents any movement other than the straight forward movement of the die-plate, reducing wear and breakage of die aligning pins.

Exhaustive tests have proved the machines capable of turning out castings with greater strength, a higher degree of precision, closer tolerances, and thinner wall sections. Smoother surfaces reduce polishing costs and make plating easier and more economical.

In designing the machines, everything possible has been done to increase efficiency of operation and to reduce lost motion. All hydraulic regulating valves have been placed on the operator's side. All high-pressure hydraulic piping is concealed in the base, and the connections are oxy-acetylene welded to prevent all possibility of leakage. Motor and pump are mounted on the base, and in casting zinc-, tin- and lead-base alloys, the motor, pump, furnace, and all burner equipment are likewise mounted.



The high-pressure hydraulic die-casting machine for zinc, tin and lead alloys.

The base itself, 48 in. wide and 182 in. long, weighs approximately 4,000 lb. It is flanged on all sides to prevent water from the die-cooling system from running on to the floor, and is reinforced with a 6-in. steel channel and cross-members to add maximum rigidity and prevent weaving. A hydraulic valve arrangement for ejecting the casting and removing the core is standard equipment on both types of machines, and they are equipped with the Vickers' hydraulic two-stage pump and control valves.

The zinc-tin-lead-alloy machine is designed in such a manner that the goose-neck or the furnace pot can be replaced without disturbing the hydraulic piping.

Automatic Carbon Arc Process applied to the construction of Aluminium Tank Cars

AUTOMATIC carbon arc welding is stated to have many advantages in the construction of aluminium tank cars. The automatic process permits faster construction and a better quality weld, together with marked freedom from distortion. This development was brought about by a desire to improve quality, not to lower costs which are practically unchanged, due to the increased flux cost cancelling the labour saving.

Since no bevelling of plate edges is required, the full thickness of metal is utilised in the welding by simply butting the square edges together, greatly simplifying the set-up of the work. The welding time per tank is noticeably shorter than previous methods, since the automatic weld is made in two passes instead of three formerly used. The fact that automatic welding permits welds of complete overlapping penetration accounts for the greatly improved quality of the weld.

Freedom from distortion, which has been a factor in previous methods of fabricating aluminium, is permitted with the automatic carbon arc method because of the faster welding this process makes possible. Very little straightening is required on round tanks welded by this process, whereas, with the previous method, considerable straightening was necessary. This advantage not only

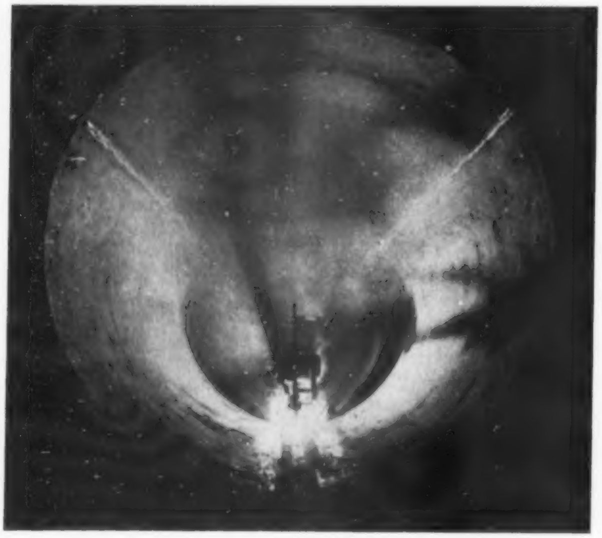


Fig. 1.—Welding an inner longitudinal seam of an aluminium tank car by tractor-type carbon arc welders.

By courtesy of the Lincoln Electric Co. Ltd.

Fig. 2.—Welding a head in an aluminium tank by the automatic carbon arc process. The tractor type automatic welder remains stationary while the tank is rotated underneath the arc.

simplifies production of the shell itself, but, because the shell is so uniformly round, the heads are readily fitted to the ends of the shell.

Accompanying illustrations show the use of automatic carbon arc welding in fabrication of aluminium tank cars. In Fig. 1 can be seen a tractor type automatic carbon arc welder welding an inner longitudinal seam in an aluminium tank. In Fig. 2 this tractor is seen welding a head on one of the aluminium tanks. The materials used in constructing tank cars of aluminium include: A bottom plate ⅞ in. thick; two sides, or top, plates ½ in. thick; and two heads ⅝ in. thick. The tanks are 78 in. outside diameter and 32 ft. overall length.

Square-edge tight butt welds are used throughout in construction. The difference in thicknesses of the butting edges is taken care of by maintaining uniform outside diameters and making up the difference by an off-set on the inside of the tank.

Three longitudinal welds, two consisting of ½ in. to ⅞in. and one of ½ in. thickness are required in constructing the shells. Two passes, one inside and one outside, are required for each longitudinal seam. The first longitudinal pass is made on the inside, with the seam properly backed up with a water-cooled copper chill bar, giving complete penetration with one pass. The second pass, made on the outside, is applied to obtain overlapping penetration and for the sake of appearance. It is made without any backing up.

In welding the heads to the shell, the head is fitted and the tank rotated under the carbon arc which welds the outer seam with the inside properly backed up with copper chill bars. Filler metal for the weld is supplied by ¼ in. aluminium wire fed into the arc. The second pass on the head weld is done manually after grooving with a chipping tool.

These aluminium tanks have, for the most part, been utilised for glacial acetic acid service. This is the basic material for the manufacture of rayon and non-inflammable film. Two of the aluminium tanks have also been put into service for carrying peroxide. These were constructed of a 99·5% aluminium alloy. The balance of the tanks, for acetic acid service, were constructed of a 97·5% aluminium alloy.

Operating Presses by High-Pressure Oil

FOR many industrial purposes, particularly that of operating presses, oil under hydraulic pressure is the most convenient transmission medium. It is usually the best to install a separate pump for each application rather than attempt to use pressure-oil from a common source. Further, such separate pumps are preferably driven direct by electric motor, the avoidance of any type of gearing being advantageous.

A high-speed high-pressure pump developed specially for such work is the Oilaulic, designed by John Mills and Co. (Llanidloes), Ltd. This is available in many sizes, delivering from 400 to 5,000 cub. in. per min., operating at speeds from 1,000 to 1,500 r.p.m., and delivering oil at pressures from 1 to 3 tons per sq. in. The pump is of the high-speed multi-ram type, and is built as a unit into its own oil reservoir, with its own filter, relief-valve, and flexible coupling, and is arranged for either hand or automatic variable delivery control.

Means of pressure or quantity control can be either speed-change, for example, by variable-speed motor drive, or by valve gear incorporated in the pump casing. Low pressure pumps in series to feed the main pumps can be fitted if required, and these are of the gear type to give, say, 100 lb. per sq. in. The pressure then automatically rises to higher values when any resistance is encountered.

Essential wearing parts are constructed of alloy heat-treated steel, the pump body, for example, being made in chrome-molybdenum steel and the rams of chrome-carbon steel of about 650 Brinell hardness. All the revolving parts are carried in Timken tapered roller bearings. The Timken equipped eccentric shafts run at 1,000 r.p.m. Interchangeability of parts is secured by close attention to standardisation in manufacture.

The pump has an extensive field of application, and, in addition to operating presses, it may be used for self-contained hydraulic machines, hydraulic machine tools, moulding presses, general direct pumping systems, and many other services requiring high oil pressures. It may also be employed as an hydraulic brake, and has, for instance, been successfully applied to the hydraulic braking of the lowering motions of electric cranes.

Rolling Metal Straight from Furnace.

THE completion of a rolling mill to produce sheets directly from hot metal is reported by the Novo-Kramatorsk Machine Building Works in the Ukraine. The new mill will produce sheets of 2–8 millimetres in thickness and 23 to 63 centimetres in width. Both steel and non-ferrous metals can be rolled. A mill of this type is already in operation in Moscow.

The operation of these mills is being studied with a view to working out the further technology of the new process and to eliminating existing difficulties and shortcomings.

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